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THE ALGAL RIDGES AND CORAL REEFS OF ST. CROIX

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ABSTRACT

The shallow coral reef and algal ridge systems on the eastern shelf of St. Croix are described and mapped in some detail. Based on present reef morphology, a section through the barrier reef in a ship channel, numerous sand probes and C^{14} dating, Holocene growth patterns of the reefs are determined and a model of Holocene evolution developed. Based on many drill cores through the algal ridges, C^{14} dating and paleoecology relative to modern ridge and reef surfaces on St. Croix, growth patterns during the late Holocene are also developed for the algal ridges.

Lithophyllum congestum, *Porolithon pachydermum*, and several *Neogoniolithon* species are the primary algal ridge builders on St. Croix. *L. congestum* requires turbulent water and high light intensity to achieve the branching form which characterizes its occurrence in the algal ridges. Also, coralline accretion rates of 3-6 mm/year necessary for ridge construction are achieved only if intensive parrot fish and *Diadema* grazing are prevented by consistent and intensive wave action. A dead coral surface or pavement at a depth of 0 to 2 m, will be colonized by crustose corallines and in turbulent water, can develop progressively by coralline algal accretion into an incipient mound, a high boiler and eventually by boiler fusion, into a linear algal ridge.

Off open, easterly shores in St. Croix, coral reefs, on building to the surface, develop algal ridges. The present morphology of the ridge-reef complex has developed primarily as a result of the control exerted by pre-existing shelf and bench levels and changing rates of Holocene sea level rise on coral-coralline and grazer ecology. Special emphasis is placed here on the importance of pre-existing shelf level in determining the form and developmental stage of ridge-reef systems.

1/Contribution no. 26 from the West Indies Laboratory of Fairleigh Dickinson University, St. Croix, U.S. Virgin Islands. This study was supported by the Research Awards Program of the Smithsonian Institution.

2/Smithsonian Institution, Washington, D.C. 20560

INTRODUCTION

The massive, wave-beaten, intertidal algal ridges of the Pacific atolls have been briefly described by numerous authors, largely beginning in the 1950's (see e.g., Emery, Tracey and Ladd, 1954; Munk and Sargent, 1954; Tracey et al., 1964; Wiens, 1962). More recently, Chevalier et al. (1968) and Littler and Doty (1974) have described the morphology of these ridges and their crustose coralline components in further detail. Elsewhere in the Indo-Pacific, the ridges are generally more weakly developed and often called algal rims (Maxwell, 1968, Great Barrier Reef; Stoddart and Yonge, 1971, Indian Ocean). Setchell (1926) emphasized the importance of crustose corallines in general on Pacific reefs.

Especially during the last 25 years, many borings have been made through the limestone caps of Pacific atolls, and some of these have also reported coralline algae as the dominant structural elements (see e.g., Gross et al., 1969-Midway). However, none of these have surficially penetrated an algal ridge. Easton and Olson (1968, 1973, in ms.) have drilled through an algal rim and dominantly coralline algal reef of Holocene age in Hanauma Bay, Oahu, Hawaii. However, this rim is apparently not intertidal and the coralline algae themselves were not studied. Some authors (Fairbridge, 1968) have considered the Pacific algal ridges as only thin algal veneers over older dominantly coral reef structures. This interpretation is probably not generally correct, but only extensive coring will settle the question.

Although relatively small coralline and coralline-vermetid frameworks, called boilers, cup reefs or microatolls have also been described for the Caribbean and tropical Atlantic (Boyd et al., 1963; Kempf and Laborel, 1968; Gessner, 1970; Ginsburg and Schroeder, 1973), "true" algal ridges have generally been considered as lacking (though see Ottmann, 1963; Rigby and McIntyre, 1966 and Glynn, 1973). More recently, Adey and Burke (1975) have described the distribution and morphology of a series of algal ridges and the associated reefs in the eastern Caribbean from the Virgin Is., Anguilla and Barbuda in the north to Grenada in the south.

The algal ridges of St. Croix are Holocene in development. They are truly algal ridges in that they are built above mean low water and not only is their upper carbonate framework dominantly crustose coralline, but their upper surfaces often support a rich fleshy algal flora of high biomass and productivity. Connor and Adey (1975) have described the non-crustose coralline algal flora of the ridges and its diversity and ecology in terms of standing crop. Adey and Vassar (1975) have examined the crustose coralline succession patterns and their growth and accretion rates, and Steneck and Adey (1975) have studied in detail <u>Lithophyllum congestum</u>, the chief builder of the ridges. In this paper, I describe the distribution, morphology and geological structure of the algal ridges and the relationship of these to the coral reefs and to bedrock geology and shelf or bench levels as well as tide levels and meteorological conditions.

The crustose corallines are the chief builders of the Caribbean algal ridges. On St. Croix, <u>Lithophyllum congestum</u> is the primary element, although in specialized situations <u>Porolithon pachydermum</u> and a complex

of Neogoniolithon species are also important. On the generic level, most of the ridge components can be identified using the keys of Adey and Macintyre (1973). However, at the species level, of the dozen that are important in ridge construction, nearly half are new species. In the older literature, a large percentage of the described species are synonyms of Lithophyllum congestum and Neogoniolithon strictum. I am presently preparing a biosystematic study of the crustose corallines of the Caribbean Sea. The new taxa used here are briefly described by Adey and Vassar (1975) and will be described in detail in the biosystematic treatment.

ACKNOWLEDGMENTS

Many persons assisted in various aspects of this project. Most important were my own colleagues and assistants P. Adey, R. Burke, J. Connor, L. Gordon, R. Steneck and J. M. Vassar, all of whom deserve special thanks for withstanding the rigors of drilling and working on the algal ridges and living amicably in the close confines of "Corallina". In addition to these colleagues, L. Gerhard, I. Macintyre, C. Moore and J. Ogden often discussed aspects of the study with me and all of the above have read the manuscript and offered valuable suggestions for its improvement. L. Bingham and his associates at the West Indies Lab helped us in many ways with the considerable technical problems of the project. Through the loan of the rock drill, which we otherwise could not have financially afforded, Clyde Moore made a major part of the geological interpretation possible. Professional diver R. Malpass and Captain Carlson of Hess Oil Company made possible the highly valuable Hess channel examination. The C^{14} dating was accomplished by R. Stuckenrath of the Smithsonian Radiation Biology Laboratory. Most of the illustrations as well as the lay up for publication were done by C. Emerick.

METHODS

The maps appearing in this paper were all constructed from aerial photographs taken from a single-engined, high-winged plane flying at altitudes of 20 to 200 meters. Best results were obtained by removing the photographer's door for better visibility and ease of camera handling, and the most useful shots were high angle obliques (60-80°). Rollie and Hasselblad cameras were used for the large negative size. Generally, shots were taken at 1/500th of a second and with ektachrome-x color or sometimes plus x, black and white. The color slides were most useful and initial mapping was accomplished on Mylar (plastic drawing paper) by projecting the color slides on a properly-oriented mapping board. Scale and angle were controlled using the 1/210,000 scale high altitude black and white verticals of Mark Hurd Aerial Surveys. Best results were obtained by photographing during the short and more or less rare periods of norther calms. Some of the high altitude commercial photographs were also taken during norther calms and were especially useful in determining the limits of the deeper reefs.

The base maps were drawn with india ink in Mylar which could then be taken underwater on a drawing board for interpretation and detail. Most

underwater mapping work was accomplished by using snorkel gear although SCUBA was occasionally employed. The Boiler Bay maps (Figs. 29-37) were completed first, and with approximately 150 man hours in the water are the most accurate. Not as much time per ridge was available for the south shore algal ridges (Figs. 16, 20, 22, 25), and especially as some of them are considerably larger than the Boiler Bay ridge, the accuracy is less. Areas not actually visited underwater are left blank. The Beach algal ridge was the last ridge mapped. With the least time available for work on that ridge, it is the least accurate in detail.

Intertidal and upper subtidal ridge elevations were estimated using a standard eye-level and stadia rod. The base of the rod was placed in a plastic tube with only a 2 mm hole for water flow to dampen wave action, the rod being set in the quieter back reef area. Tide levels were determined at the West Indies Lab dock in Tague Bay. Two, four to five hour parallel tidal measurements were made at Boiler Bay and at the Fancy-Robin area on the south shore to see if a difference in tide time existed. No difference was found. The tides are discussed in detail below.

Drilling on the algal ridges was accomplished using a gasoline-driven hand held Acker Drill Company "pack-sack" and both diamond and carbide bits. Most of the cores taken on the south shore algal ridges were 29 mm in diam.; most of those taken in Boiler Bay were 20 mm in diam. Flushing water was obtained with a 3 hp, gasoline-driven pump and holes were not cased.

Two people could operate the drill on a ridge with some difficulty, but three or preferably four were required for an efficient operation. Usually a platform about two meters square and 1-1/2 meters high was set up on the ridge to hold the core boxes, rods, pump, gasoline, tools etc., and drilling was accomplished standing on the ridge itself. Quiet days were usually chosen for drilling, though on the larger ridges some hazard to equipment and personnel remained on all but exceptionally calm days. Once the platform was set up and the hole started, the drillers had something to hold onto and there was usually not a major problem with the waves. The most difficult times were setting up and breaking down. On several occasions all of the gear was dumped in the water and the operation had to be suspended until the engines could be thoroughly serviced. Also occasionally a wave would catch one of us off balance and the resulting bounce on the ridge would result in a few scratches and *Echinometra* spines.

In the Boiler Bay algal ridge, we drilled 32 holes, 13 through to the underlying basement at 2 to 4 meters. On the more difficult south shore ridges, we drilled 7 holes, two of which went through to basement at 8 to 9 meters. Once the platform was set up there was usually little difficulty in drilling in the upper 3 meters. Core recovery varied widely from 80 to 90% in solid coralline to nothing for as much as 3 meters in sand-filled cavities. On the other hand below 6 meters increasing difficulty was encountered, and we often spent as much as a whole day retrieving our bit from one meter of drilling in the 6-9 meter range. A more powerful water pump and an A-frame or tower with a block and tackle would probably alleviate this problem.

Interpretation of the cores was achieved with 20 μm thick ground sections. In coralline cores the following four elements were determined in slides Lithophyllum congestum, Porolithon pachydermum, Neogoniolithon spp. and Tenarea sp. More detail could have been obtained in identification, but this was not considered necessary at this point in the study. Coral species were usually determined from the hand specimens of cores. Both cores and sections are housed in the coralline collection at the National Museum of Natural History in Washington, D.C.

Surficial blocks of ridge material 30-50 cm on a side were often obtained, sometimes with considerable difficulty, using a crowbar and large chisels. In Shark Reef in Boiler Bay we created a slot in the front of the ridge about 0.6 meters wide, 1.6 meters into the ridge and one meter in depth using a combination of chopping and drilling. The slabbing of these blocks on a rock saw helped considerably in our interpretation of the cores.

Twenty-eight C^{14} dates were obtained, 17 on coral and 11 on coralline. Although all but one of the coral dates are consistent with each other and the interpretation presented here, the oldest being 4360 years B.P. ± 90, the coralline dates are irregularly young. However, these ages all occur below the envelope for the Bermuda sea level curve of Neumann, as discussed below. A single Acropora palmata date from Boiler Bay at 4900 years B.P. placed several feet above the sea level standard. However, a careful check of this specimen showed that the gray-darkening characteristic of subaerially-weathered coral was present. We have interpreted this specimen as part of a supra-tidal storm berm such as are quite common on eastern St. Croix today. The position of sea level in the ridge cores was determined by our sea level indicator Lithophyllum congestum (see Steneck and Adey, 1975).

Through the courtesy of the Hess Oil Refinery in St. Croix, we were able to dive and take many subsurface samples of Long Reef, seaward of the refinery, where the 19-meter deep ship channel sections the reef and extends 6 meters into the basement. C^{14} dating of large coral samples from this section forms the basis for our time interpretation of the coral reefs.

Our 41-foot, ketch-rigged, motor-sailor trimaran "Corallina", with a relatively large central lab and bunks for six served as our home, field transportation and base of operations during the course of this study.

PHYSICAL ENVIRONMENT

All of the known algal ridges on St. Croix occur east of Canegarden Bay (Fig. 1), where the bed rock is mostly weakly metamorphosed, upper Cretaceous, deep water sand and mud stone of the Caledonia Formation. Whetten (1966) describes this formation in some detail. The westernmost ridge, at Vagthus Point, on the south shore we have not studied in any detail. Apparently it lies on a limestone member of the Judith Fancy Formation. We have also seen a small ridge off Spring Bay from the air,

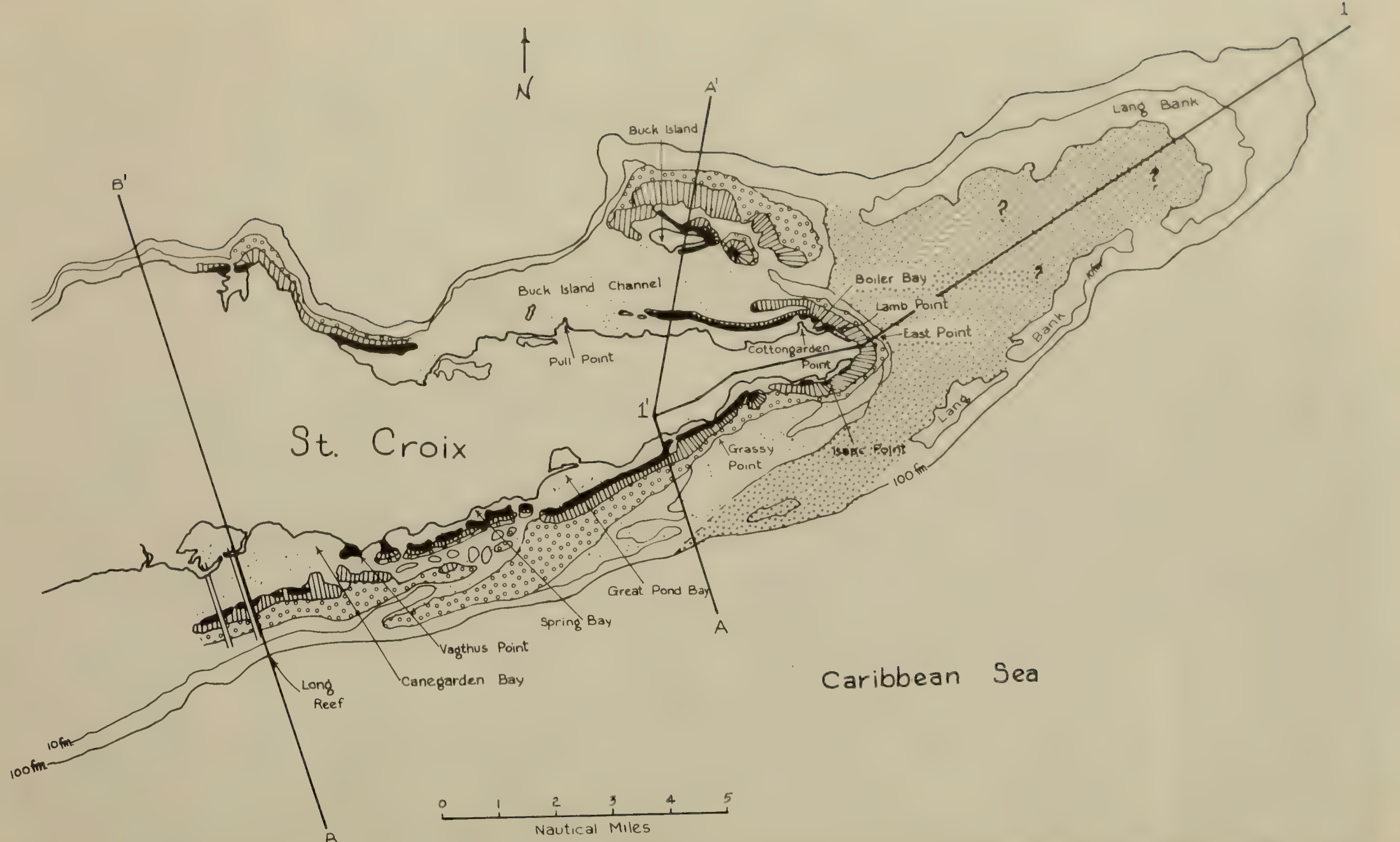


Fig. 1. Major reef-ridge environments on eastern St. Croix and positions of "shelf" sections. ■ reef flat or algal ridge, +0.5 m to -1 m; ▥ dominantly *Acropora palmata* upper fore reef; ⚬ dominantly *Montastrea annularis* and *Diploria* spp., deeper fore reef; ⁘ *Meandrina* hard ground; ⁛ sediments, dominantly sand size and bioclastic.

but have not visited this ridge. The remaining ridges lie east of Great Pond Bay. The smallest of these, one at East End Bay (Fig. 4), and another north of Buck Island, lie close to exposures of the Caledonia Formation, but the nature and depth of their immediate basement is unknown.

Three of the large south shore ridges, Fancy, Robin and Isaac and the incipient ridge at Hughes Point (Fig. 4), lie off exposures of the point-forming East End Member of the Caledonia Formation (Whetten, 1966). All of these ridges are apparently developed on hard shelves cut in the bed-rock at the minus 8-12 meter level. The fourth major south shore ridge, Beach ridge, apparently lies on a similar bench cut on a fault scarp. Adey and Burke (1975) discuss in detail the control exerted by bedrock geology on shelf level and consequently algal ridge distribution in the eastern Caribbean. This is discussed further below in terms of ridge placement on St. Croix.

The algal ridge in Boiler Bay is unusual in several respects. A small part of it is apparently developed on ridges of the Caledonia Formation. However, the major lobes of the ridge are less than 3 meters thick and they are formed on a bench of Caledonia boulders. These boulders are the lag deposit or remains of a rapid-flow or colluvium derived from the Caledonia probably during the last 100,000 years of the late Pleistocene.

Formal meteorological data were not taken at any locality on the east end of St. Croix during 1973-74. However, "Corallina" has both an anemometer and a wind direction indicator. During our stay on St. Croix from late 1972 to early 1974, at least some members of our group had occasion to be in the field virtually every day of the period, and usually we were concerned with both wind direction and strength. The following wind and sea description is based to some extent on this subjective familiarity.

The easterly trade wind is markedly constant on eastern St. Croix and during our stay it blew at 10-20 knots from ENE to ESE better than 95% of the time. According to the U.S. Navy Marine Climatic Atlas of the World (1955), this part of the Caribbean experiences two peaks of wind velocity, one in June and July and the other in December and January. This was roughly true during our stay, though the autumn of 1973 was extraordinarily windy. During the spring and autumn, continental fronts or northers sometimes reach St. Croix. Usually, this results in a shift of the wind into the north or northeast, where it blows at 10-15 knots, rarely 20 knots, for about a day. After this the wind often falls to light and variable for a day or two before picking up to a strong easter again. During the autumn of 1972 and then again in the spring of 1973, 3-4 northers followed this pattern. On the other hand, in the autumn of 1973 and then again in the early spring of 1974, there were few northers and for those that did pass through, the wind merely shifted from E to NE and back without markedly changing in intensity. During this latter period the wind was also occasionally well into the SE. However, in late April 1974, a strong front passed which caused the wind to blow from due north for one day at about 15-20 knots, and a second at 10-15 knots. This two-day norther was then followed by four days north to east winds at about 5-10 knots. Perhaps there is also a diurnal cycle, relatively

light during the night, and stronger during the day, but this is not marked on eastern St. Croix. It was often my impression that the wind on the exposed south shore was lightest from about 1600-1800, picking up again to mid-day strength by 2100-2200.

The constant offshore sea resulting from this wind pattern is short and steep and mostly from 1-2 meters in height. Rollers, the large swells resulting from intense northers in the southeast Atlantic and often experienced on the northern coasts of the northern Virgin Islands did not occur during our stay in St. Croix. They are apparently largely blocked and dissipated by the northern Virgin Islands. Even during the calm periods with low mid-day tides, the ridges at heights of 30-50 cm above mean sea level would take at least a wetting sea every few minutes. It is possible that an extended calm, like that experienced in April 1974, in conjunction with a period of daytime low water springs might result in serious desiccation and kill-off of algae and coral on the ridges and reefs. However, this did not happen on the algal ridges during the autumn of 1972 to the spring of 1974 period.

Water clarity around the ridges and reefs is usually largely dependent on the intensity of wave action and the resulting suspension of fine carbonate sediment. During rough periods, visibility is only 4-6 meters, while after a few quiet days it can be 15-20 meters. The quantity of plankton in the water appears to be highest in the summer and, as this is often a relatively rough time, the visibility tends to be particularly poor.

During the period that we were mapping and leveling the ridges (early April to late June, 1973), we kept a continuous record of tide at the West Indies Lab dock by simply reading sea level on a meter stick attached to the dock. This was read every one to two hours during the day and every 3-4 hours at night throughout April and May. The reading was more desultory during June, but by late June, John Adams and Jay Kunin of the Laboratory had installed a computerized guage at the dock. This record was not continuous, largely because of other computer use and technical problems, but in conjunction with our continuous reading in May and June, it provides a fairly complete picture of tidal patterns during July and later in December and early January.

During spring tides, which roughly correspond with the full and new moons, the tidal pattern is markedly diurnal and usually has a range of 30-35 cm. The neap tides, with a range of about 10-15 cm, are sometimes clearly semidiurnal. More often, however, the neaps are rather irregular with one high and one low strongly dominating the other. The period of neaps is often rather sharply begun as a "no tide day", with the low part of the diurnal cycle being clipped-off at or slightly below mean tide level and then remaining within a range of 2-3 cm for 10 to 12 hours. Our ridge leveling was based on a position for mean low water springs established from our data for April and May. A long term record might require some adjustment of this value, but it is probably correct to within ± 2 cm, which is likely as good as our accuracy of ridge leveling. Figure 2A shows a typical springs to neaps cycle from 1973, along with the relative positions of the higher parts of several algal ridges.

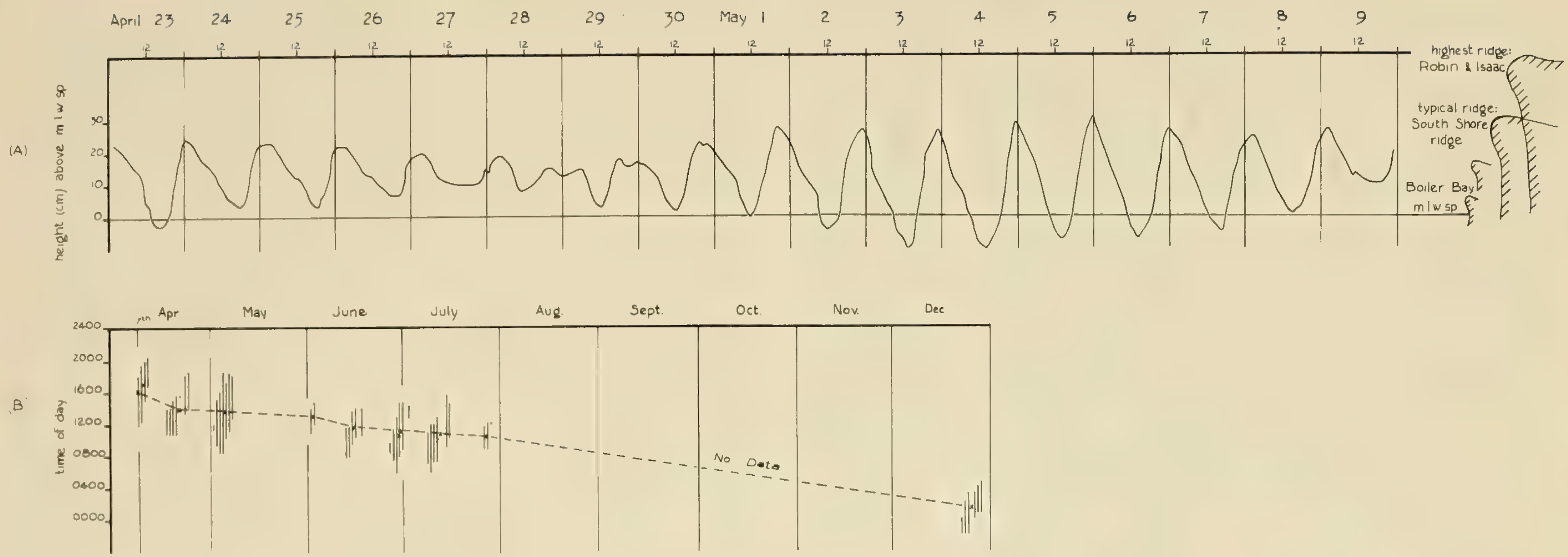


Fig. 2. Typical tide patterns on eastern St. Croix. (A) Bi-monthly cycle at West Indies Laboratory dock for late April and early May 1973. Level of mean low water springs based on tides for April to June, 1973. (B) Times of occurrence of tide levels at or below mean low water springs. April-December, 1973.

The degenerating Boiler Bay ridge crests range from about 17 cm above mean low water springs to mean tide levels. The larger, south shore ridges have crests that range from about the position of mean sea level to levels of mean high water springs. The very active Isaac and Robin ridges have many of their crests at or above mean high water springs and their highest crests are about 20 cm above that level or nearly 10 cm above the highest tide level recorded in this study. (Adey and Burke (1975) describe ridges in the Lesser Antilles ranging up to about one meter above mean low water.)

In April 1973 the period of low water springs was centered about mid-afternoon, with the early part of the 7-day phase being centered about early afternoon and the later days being centered about 1800 (Fig. 2B). By June, low water springs were centered around noon, by mid-July, they had migrated to about 1000, and finally in late December they were centered about 0300. Thus, at the present time at least, low water springs occur in mid-day during the early summer and during midnight in the winter. Glynn (1968) discusses the effects of a similar tidal pattern on mass mortalities of reef organisms in rather protected environments in Puerto Rico.

According to the World Atlas of Sea Surface Temperatures, Navy Hydrographic Office (1944), the offshore sea surface temperatures in the vicinity of St. Croix range from 25° C in February to 28° C in July. Behind the reefs and ridges, especially during quiet weather, these values are often modified and the lagoon normal maximum range especially near shore is about 23-30° C.

The east end of St. Croix is rather dry with a yearly rainfall of about 30 inches, much of this being concentrated in the rainy season from June to December. Occasional very heavy rains may reduce the salinity below 35°/₀₀ near shore where intermittent streams enter the lagoons. In the vicinity of the reefs and ridges, salinities probably only very rarely go below 34°/₀₀.

DISTRIBUTION OF ALGAL RIDGES AND CORAL REEFS

The locations and depth profiles of the major reef and ridge environments on the shelf of eastern St. Croix are shown in figures 1, 3, 4. We have only visited a single locality on Lang Bank, and it consisted largely of a rubble-covered carbonate pavement with only scattered head corals and very few *Acropora palmata*. As I will elaborate below, it would appear that Lang Bank, now at 9-18 meters depth, was constructed on the shelf edge at 25-30 meters during the Holocene. We have only seen the western parts of the *Meandrina* pavement on the eastern shelf (Fig. 9), and its extension over the whole shelf remains to be examined. The two channels that were cut across Long Reef on the south coast (Fig. 1) extend into the industrial complex that now occupies Krause Lagoon. The eastern channel which enters the Hess Refinery, exposes the entire Holocene, the Holocene-Pleistocene contact, and the uppermost 7 meters of the Pleistocene. Much of our time-frame and stratigraphic interpretation of the coral reef system on St. Croix is based on this section.

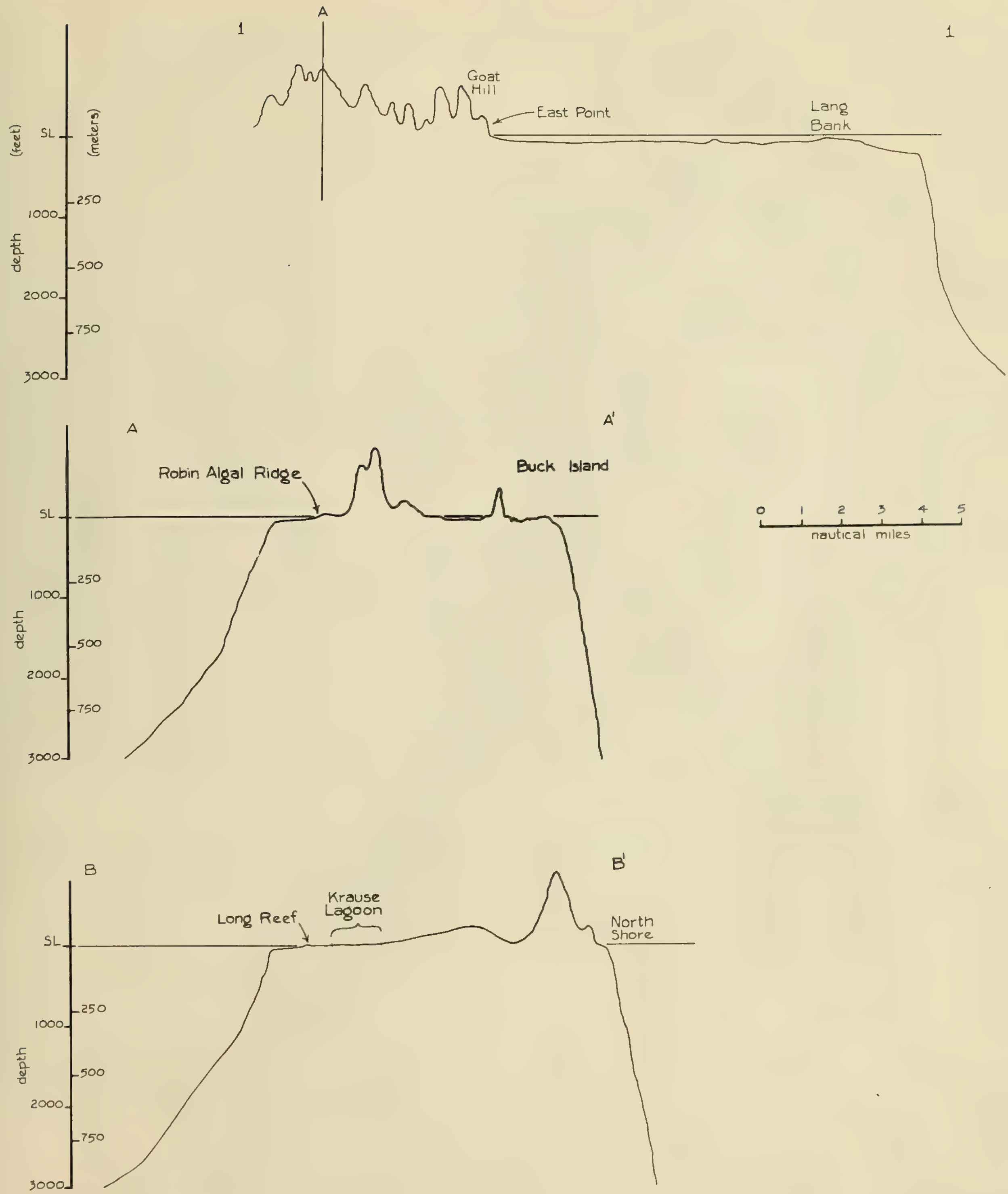


Fig. 3. "Shelf" sections on eastern St. Croix, see figure 1 for locations.

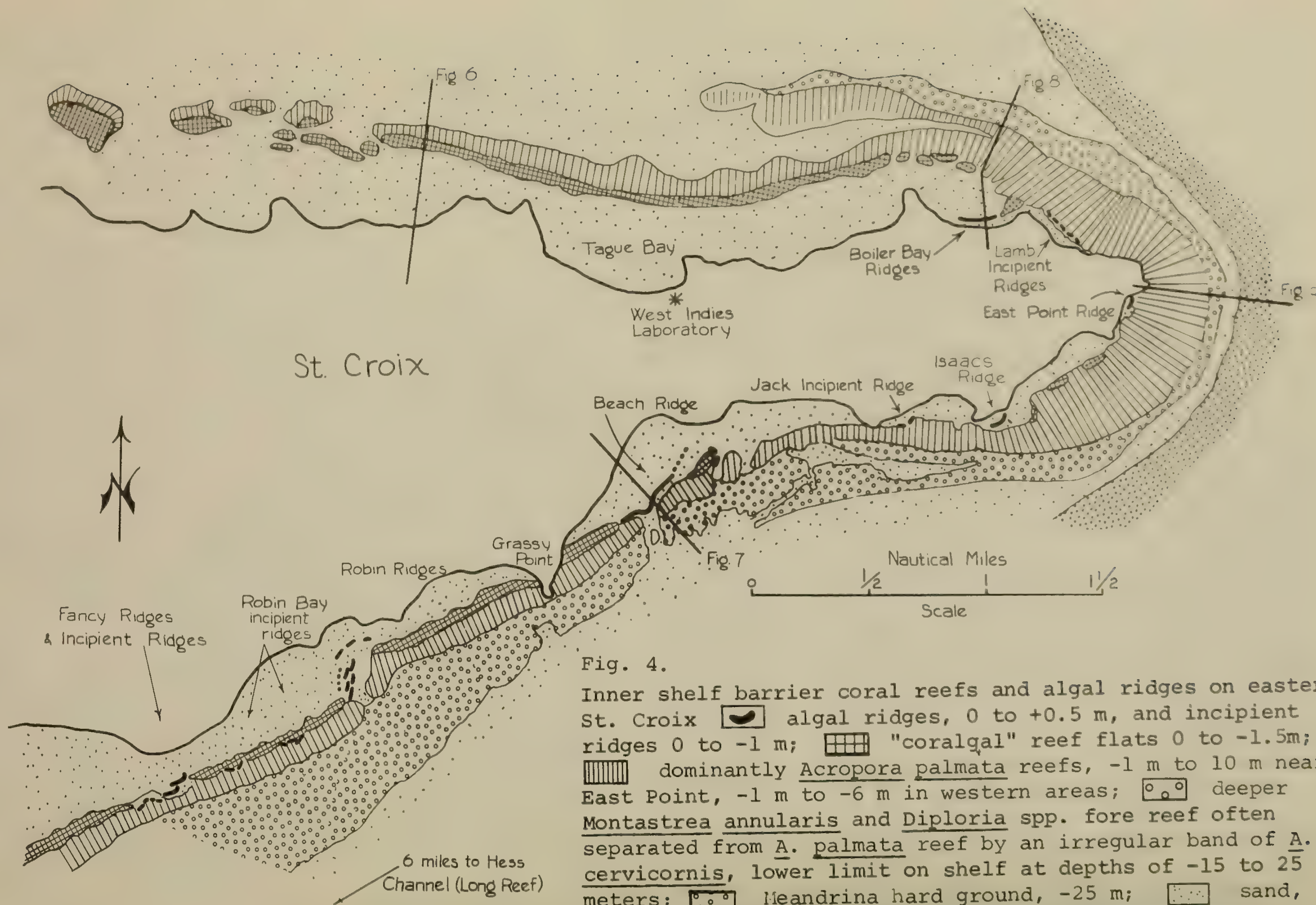


Fig. 4.

Inner shelf barrier coral reefs and algal ridges on eastern St. Croix algal ridges, 0 to +0.5 m, and incipient ridges 0 to -1 m; "coralgal" reef flats 0 to -1.5m; dominantly *Acropora palmata* reefs, -1 m to 10 m near East Point, -1 m to -6 m in western areas; deeper *Montastrea annularis* and *Diploria* spp. fore reef often separated from *A. palmata* reef by an irregular band of *A. cervicornis*, lower limit on shelf at depths of -15 to 25 meters; *Meandrina* hard ground, -25 m; sand, -2 to -6 meters in lagoon, -15 to -25 meters on shelf.

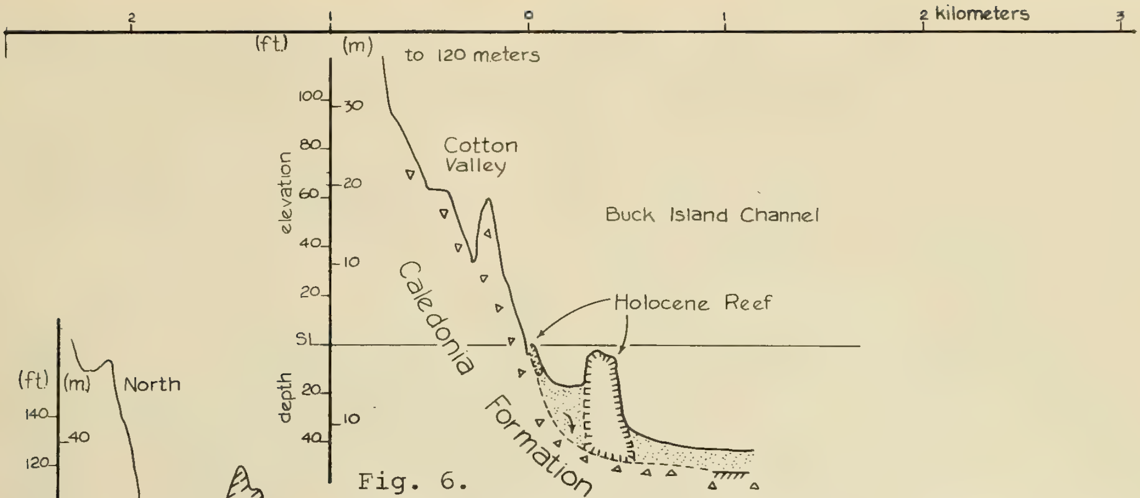


Fig. 6.
Section through northern barrier reef as shown in Fig. 4. Sediment depths in lagoon and Buck Island channel (and in Figs. 7-9) are based on probes.

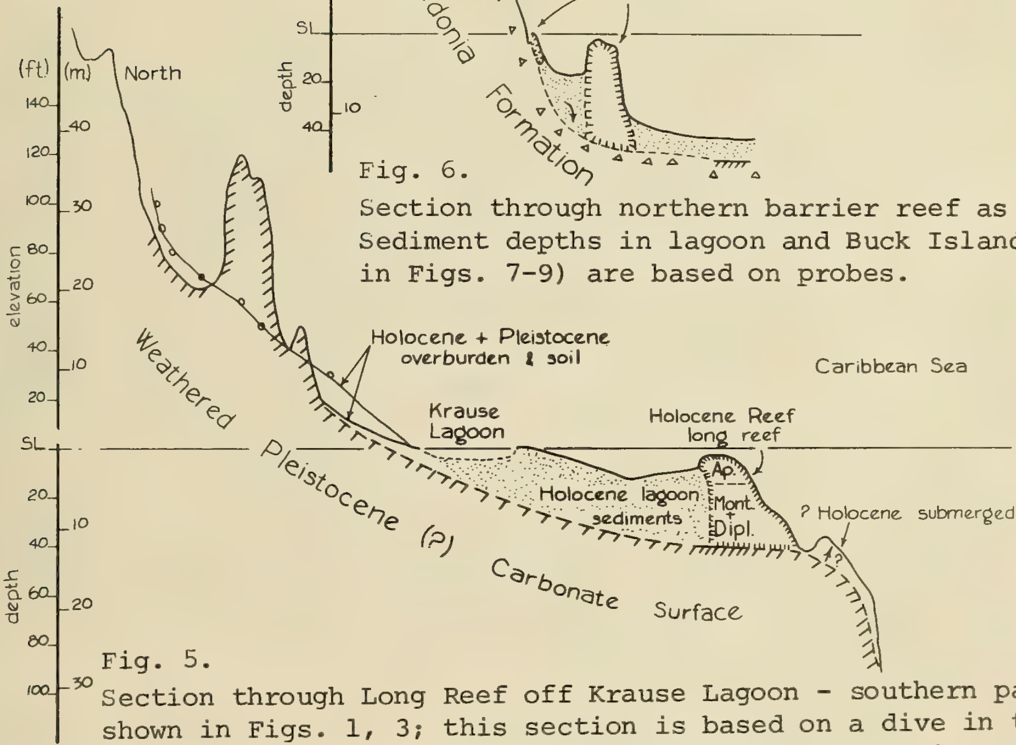


Fig. 5.
Section through Long Reef off Krause Lagoon - southern part of BB' shown in Figs. 1, 3; this section is based on a dive in the 60-foot deep ship channel through the reef. Elevations, depths and scale are based on the USGS topographic sheets and C&GS chart 905. In this and the following figures: verified basement; assumed basement or interface.

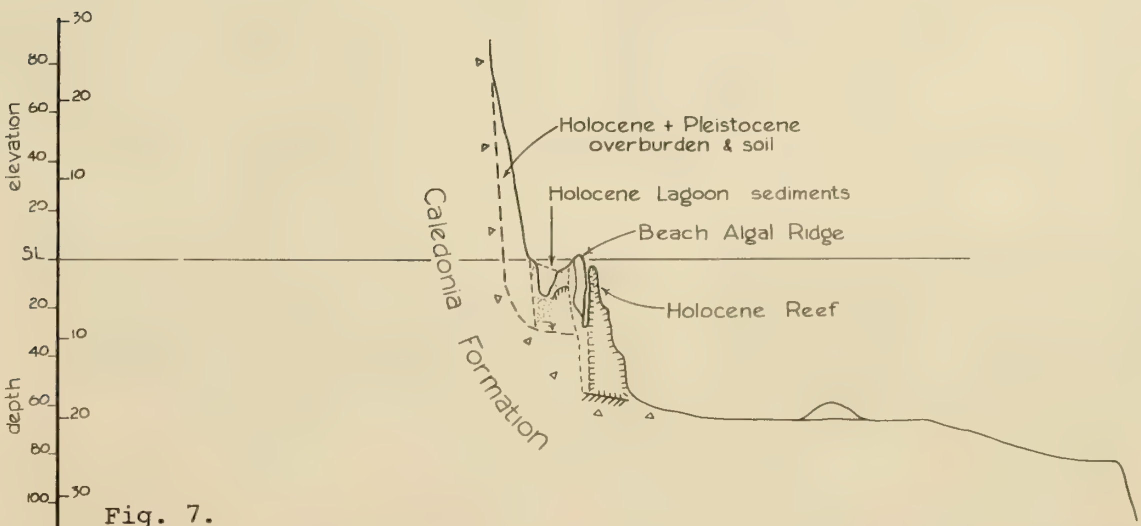


Fig. 7.
Section through barrier reef and Beach algal ridge just east of Grassy Point (Fig. 4). Sediment depths between reef and ridge based on probes; indicates hard basement > greater depth shown.

Under Long Reef the shelf is about 12 meters deep, and just outside the reef it is about 13 meters deep (Figs. 5, 12). No raised platform, raised terrace or raised biohermal structure is evident beneath this reef. Elsewhere, where information was obtained on basement depths inside and outside, but not directly beneath the reef structure (see e.g., the reef sections shown in figures 6-9), I have assumed that the reef structure is lying on a more or less gently-sloping pre-Holocene topography and not on ridge or mound like reef or aeolian structures.

The shelf itself is relatively shallow (10-15 m) at its western ends both in the western Buck Island Channel on the north (Fig. 6) and along the south shore from Krause lagoon west. Further east, around Grassy Point (Fig. 4) the shelf lies at about 15-18 meters under the reef and about 20 meters outside (Fig. 7), while to the north off Boiler Bay, a shallow shelf in the Bay slopes to about 20 meters just offshore and has given rise to a triple-reef complex (Fig. 8). At East Point, outside the reef, the shelf is about 24 meters in depth and, although there is no direct evidence, presumably it is 18-20 meters under the reef itself (Fig. 9). The reefs lying on the inner shelf from Pull Point in the north and Long Reef in the south eastward to East Point show a general pattern of decreasing maturity. In the west the reef flats are relatively broad; they decrease in width eastward and off Boiler Bay in the north and Grapetree Bay in the south they become fragmented. From Isaac Point around East Point to Lamb Point, reef flats are virtually absent.

Thus it appears to be shelf depth (i.e., position of the pre-Holocene surface relative to Holocene sea levels) that has influenced the rate and pattern of development of the inner shelf barrier reef system on St. Croix. The pattern of development in Long Reef (discussed below), as shown by C^{14} dating and coral paleoecology, indicates why this has happened. The reason for the west to east shelf slope may lie in carbonate sedimentation patterns, i.e., a general east to west reduction in energy along with increased carbonate sediment load, at high sea level stands during the later Pleistocene, though structural control is also possible. The immediate shelf surface probably is an age equivalent to the massive very shallow marine formation at about 2 meters height from Hamm's Bluff to Cane Bay on the northwest shore of St. Croix. We have two coral dates on that formation both at 20,000 years B.P. However, these are probably both "dead", affected by more recent carbon, and are likely about 120,000 years B.P. in age. As I discuss below, higher sea level stands probably would not have allowed the development of massive Holocene reef systems on this shelf, much as the present situation in the southeastern part of the northern Virgin Island shelf (see Adey and Burke, 1975).

The positions of the coral reefs as well as the major algal ridges and the larger sublittoral or "incipient" algal ridges are shown in figure 4. As was pointed out above, there are small ridges on the north side of Buck Island and on the south shore outside of Spring Bay and at Vagthus Point. These were not studied in detail and will receive only occasional reference here.

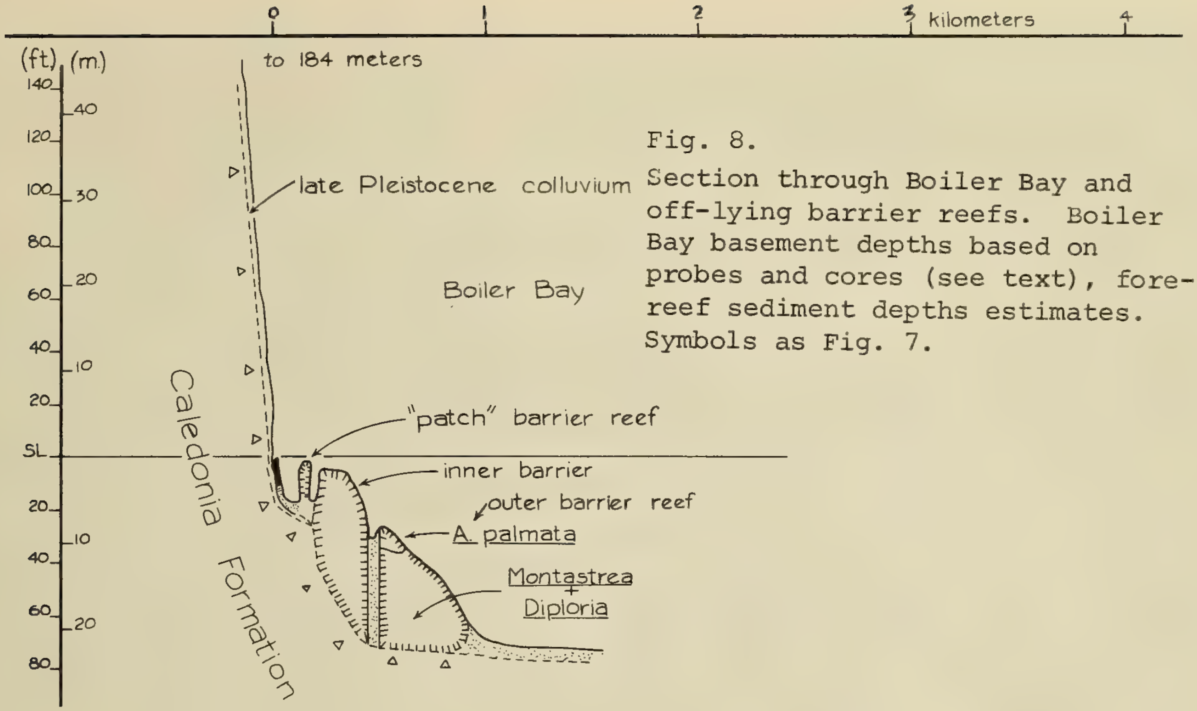
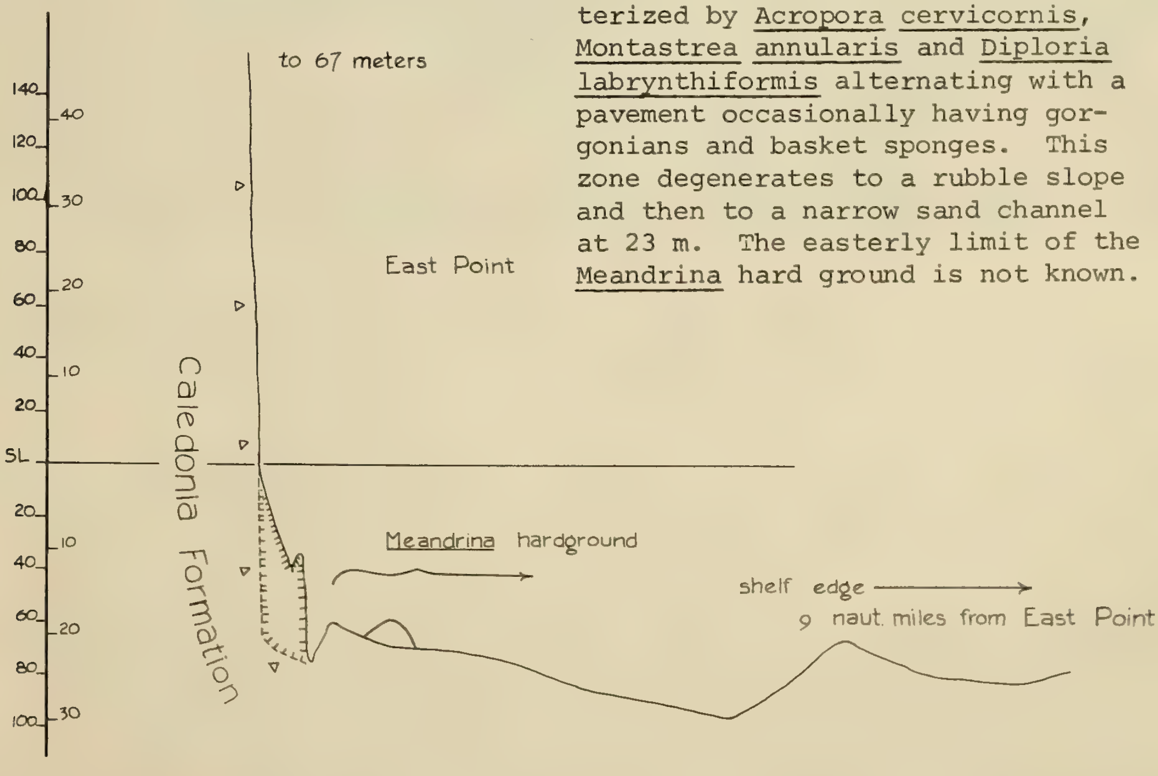


Fig. 8.
Section through Boiler Bay and off-lying barrier reefs. Boiler Bay basement depths based on probes and cores (see text), fore-reef sediment depths estimates. Symbols as Fig. 7.

Fig. 9.
Section through reef at East Point (Fig. 4). Basement depth estimated from previous sections. From -2 to -13 m, the reef is dominated by <u>Acropora palmata</u> on undercut blocks of <u>A. palmata</u> pavement separated by rubble-filled grooves and basins. A narrow rubble-sand band with gorgonians occurs at -13 m. The rather narrow deep fore-reef is characterized by <u>Acropora cervicornis</u>, <u>Montastrea annularis</u> and <u>Diploria labrynthiformis</u> alternating with a pavement occasionally having gorgonians and basket sponges. This zone degenerates to a rubble slope and then to a narrow sand channel at 23 m. The easterly limit of the <u>Meandrina</u> hard ground is not known.



CORAL REEFS

The "reef flat" shown in figures 4, 10 and 27 is generally dominated by *Acropora palmata*. While some colonies of *A. palmata* are alive and extend to near mean low water springs, a large part of the flat or pavement surface at 0.5-1 m below mean low water is constructed of a matrix of dead arms of *A. palmata* coated with crustose coralline, especially *Neogoniolithon megacarpum* and to a lesser extent *Neogoniolithon imbricatum* and *Porolithon pachydermum*. The outer edge or crest of the flat also tends to have a high proportion of *Millepora complanata*, and the back flat sections, as they deepen into the lagoon (at 2-6 meters), frequently also have abundant *Montastrea annularis*, *Diploria* spp., *Porites porites*, and the small form of *Acropora cervicornis*. The *Acropora palmata* fore-reef is usually strongly dominated by that species. It extends to depths of about 13 meters at East Point, the lower boundary gradually rising to the west probably because of decreasing light due to turbidity and perhaps partly due to lessened wave action. Further west on the Tague Bay reef, on the south of the Buck Island Channel, and on the western parts of the south shore, the lower depth limit is 5-8 meters. The upper parts of the *A. palmata* fore reef, especially in highly turbulent areas, often consists of extensive dead areas or pavements, heavily coated with crustose corallines, mostly the same species dominating on the reef flats (Fig. 11). These pavements, which are essentially *A. palmata* frameworks extensively filled with crustose coralline and apparently without major amounts of submarine cementation, can give rise to the "incipient" algal ridges discussed below.

In the relatively quiet Buck Island Channel, an irregular band of *Porites porites* often extends from the base of the *A. palmata* fore reef to the sand channel floor at 10-12 meters. However, further east and on the south shore, this zone is usually occupied by *Acropora cervicornis*. The *A. cervicornis* band can be extensive, tens of meters wide, or on the other hand sometimes it exists only as scattered patches. From the lower end of the *A. palmata* fore reef to the sandy shelf, the dominant coral is usually *Montastrea annularis*, though *Diploria* spp. are common and scattered *A. cervicornis*, with an occasional *A. palmata*, also occur. Occasionally a marked spur and groove pattern occurs in the lower fore reef and sometimes it extends partly into the shallower *A. palmata* zone (see Fig. 27). The lower boundary of the deeper fore-reef is sometimes marked by a more or less abrupt drop of 1-2 meters to the sediment interface.

The flat, sandy shelf is found directly below the *Montastrea-Diploria* deep fore reef and this generally extends almost to the shelf margin. Off East Point, however, as shown in figure 4, the sand band is narrow, and the shelf beyond is coated with a pavement or hard ground. The dominant coral on the hard ground is *Meandrina meandrites*, although *Montastrea cavernosa*, *Siderastrea siderea*, *Diploria strigosa*, *Dichocoenia stokesii* and *Zoanthus* spp. also occur. Approximately 75% of the surface is a coral-bare pavement with abundant gorgonians and sponges. The subsurface nature of the hard ground was not studied. The wrapped-back westward-curving pattern of the hard ground and sand boundary seen in figure 4 suggests that wave and current action on the shelf gradually moves much of the carbonate sediment produced on the hard ground westward.

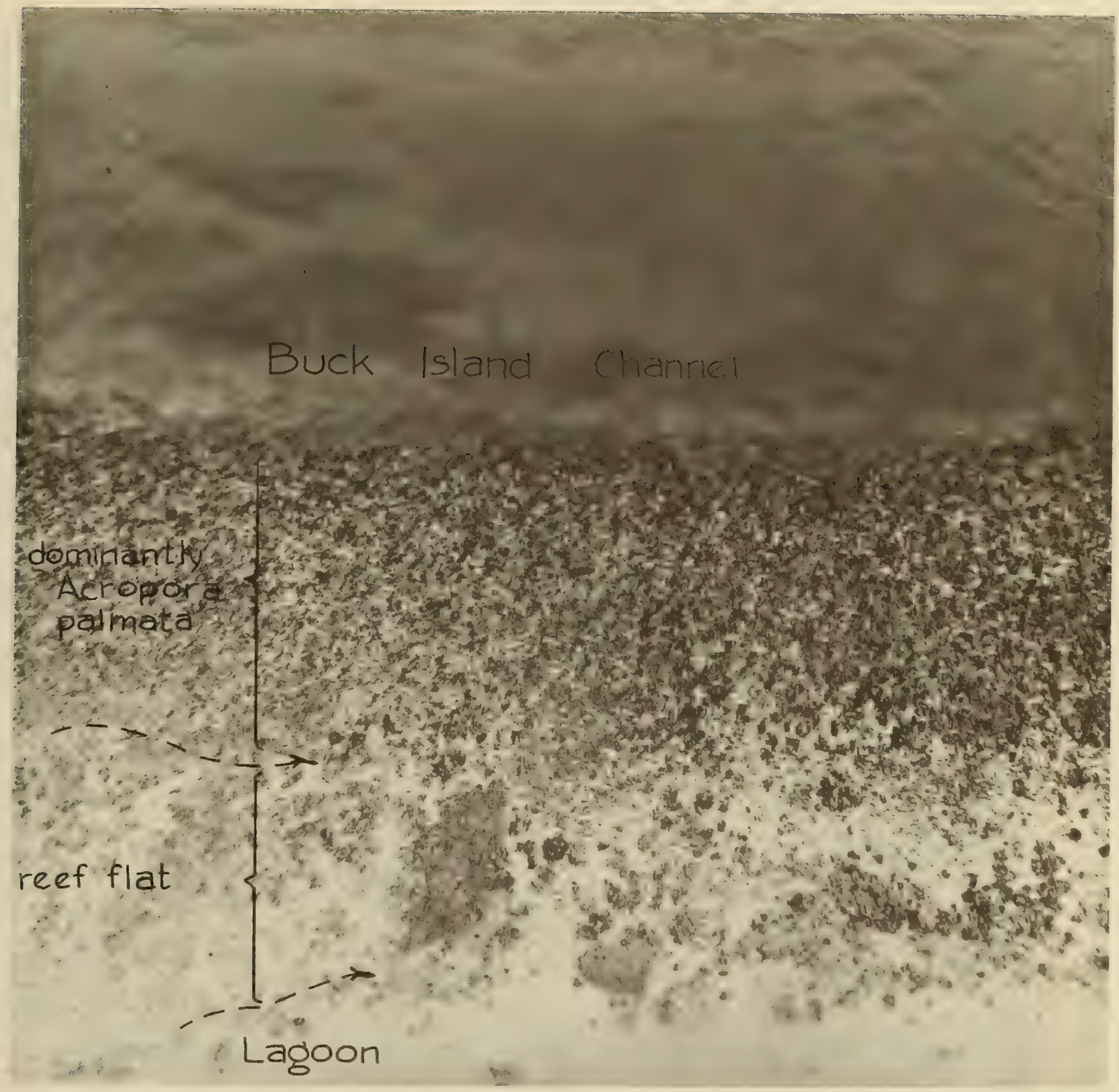


Fig. 10. Northern barrier reef off western Tague Bay (see Fig. 4). This aerial photograph was taken looking north towards Buck Island channel at an angle of 60-80° from horizontal. A section through this area was described by Ogden et al. 1972. The reef is about 140 m wide here.

Fig. 11. Aerial photograph of Lamb Incipient algal ridge. P extensive <u>Acropora</u> <u>palmata</u> pavements. A small incipient algal ridge lobe. No well-defined reef flat exists in this area.

When this combines with the probably much greater quantity of sediment pouring off the A. palmata and Montastrea reef, formation of a hard ground is prevented by an excessive "bed-load" of carbonate sand and silt. Thus, the westward-widening sand channel off East Point (Fig. 4). The Meandrina hard ground is especially interesting and in need of extended study because of its possible importance to shelf-building in the Antilles.

A detail of the Hess channel section through Long Reef is shown in figure 12. This reef appeared to be a rather loose aggregation of coral fragments, although this might have resulted from blasting in the channel. In the upper part of the section, the coral was frequently coated with up to 1 cm of coralline algae and Homotrema, however, there was no evidence of either inter-fragment connection of crusts or of secondary cementation. In the lower section, there was no evidence of encrustation on the coral, while a considerable amount of surface boring was present. The dates shown were taken from the quite "clean" centers of large coral pieces.

The upper part of the underlying carbonate basement is well cemented and consists of coralline-coated Porites porites and mollusc shell fragments in a matrix of fine-grained carbonate. The upper surface immediately below the reef is blackened to a depth of 5-10 mm and pitted much like weathered carbonate surfaces subaerially exposed on St. Croix. Ian Macintyre (Smithsonian Institution) ran an x-ray diffraction analysis on a blackened Porites porites fragment from this crust finding no aragonite and with low-magnesium calcite dominant, further indicating that is is a subaerially weathered Pleistocene surface. This Porites-shell member grades downward into a poorly indurated carbonate clay with scattered small shell fragments having a trace of intermixed non-carbonate minerals.

The C^{14} ages shown in figure 12 are plotted as a function of depth below present sea level in figure 13. The Neumann sea-level curve for Bermuda (Neumann, in ms.) is also plotted for reference, assuming negligible tectonic activity on St. Croix during the Holocene. This reef was apparently not initiated until about 2500 years after sea level rose over its foundation, probably the time required to clear the Wisconsin regolith from the shelf surface and move it west beyond Krause lagoon. At this point, 4400 years B.P., the water depth would have been about 7 meters, and at this relatively turbid location the dominant corals would be Montastrea and Diploria spp. For about 1400 years thereafter, sea level rose at 2.4 mm/year exceeding the rate of reef growth, and the average water depth from 3000 to 4000 years B.P. was increased to about 9 meters. The resulting rate of reef growth for this interval 1.3 mm/yr, is close to that obtained by Goreau and Land (1973) for reef growth at 25 m on the north coast of Jamaica. At about 3000 years B.P., sea level rise slowed to about 0.4 mm/year and continued reef accumulation shallowed water depths over the reef. At about 1000 years B.P. Acropora palmata became established on Long Reef at a depth of about 4.5 meters, reef upward growth became quite rapid (15 mm/year) and depths close to the present reef flat (-1 meter) would have been reached at about 500 years B.P. Reef flat accumulation at this relatively quite turbid, westerly location, with new reefs forming to the east, is probably very slow as shown in figure 13.

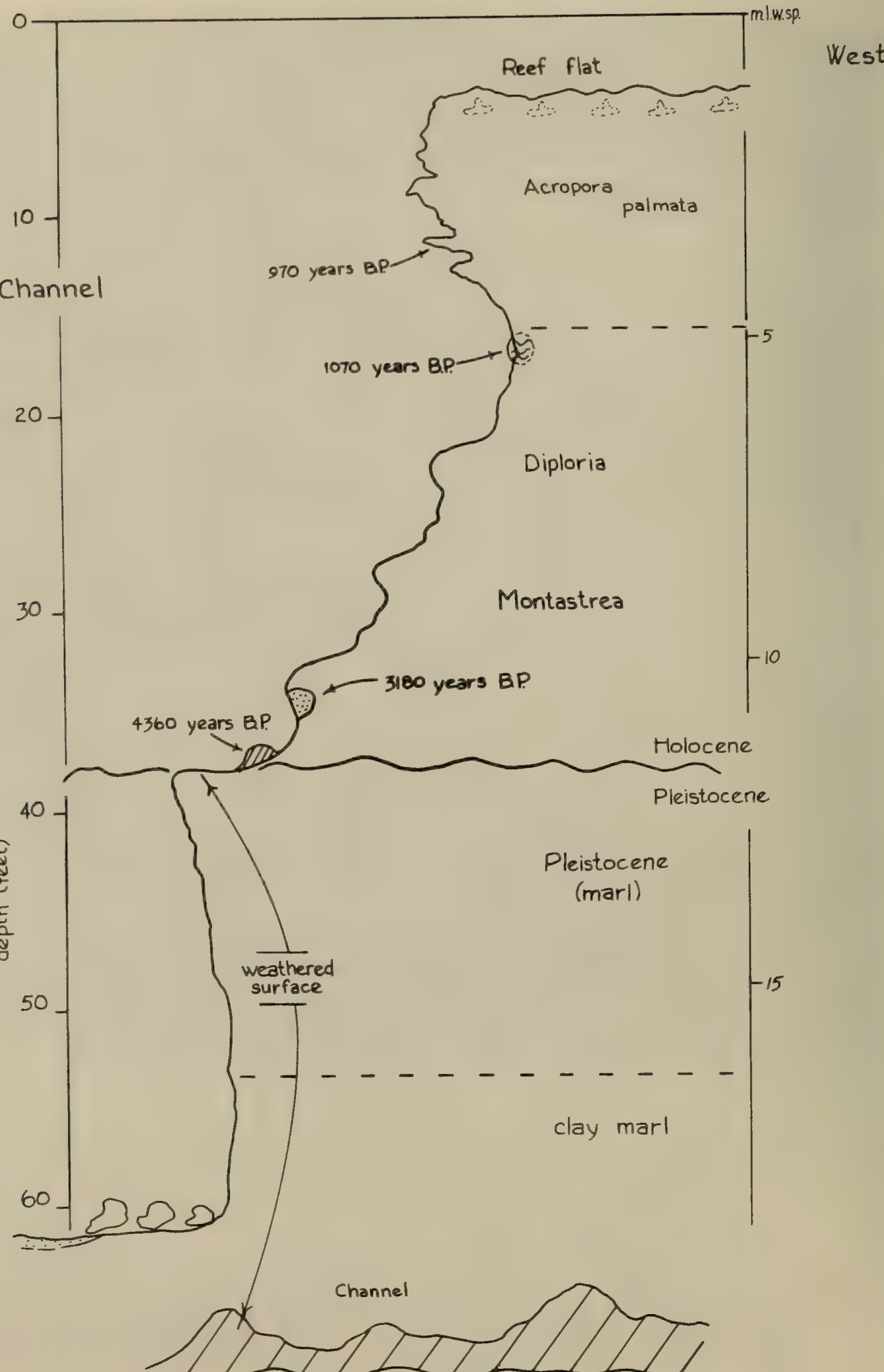


Fig. 12.
West wall of the ship channel cut through Long Reef off the Hess Oil Refinery at Krause Lagoon. Collections were made independently by four divers and pooled later. Almost all samples taken from 4.5-13 m were Diploria ( ) and Montastrea ( ). One Siderastrea siderea ( ) was collected. Most of the samples taken above 4.5 m were Acropora palmata.

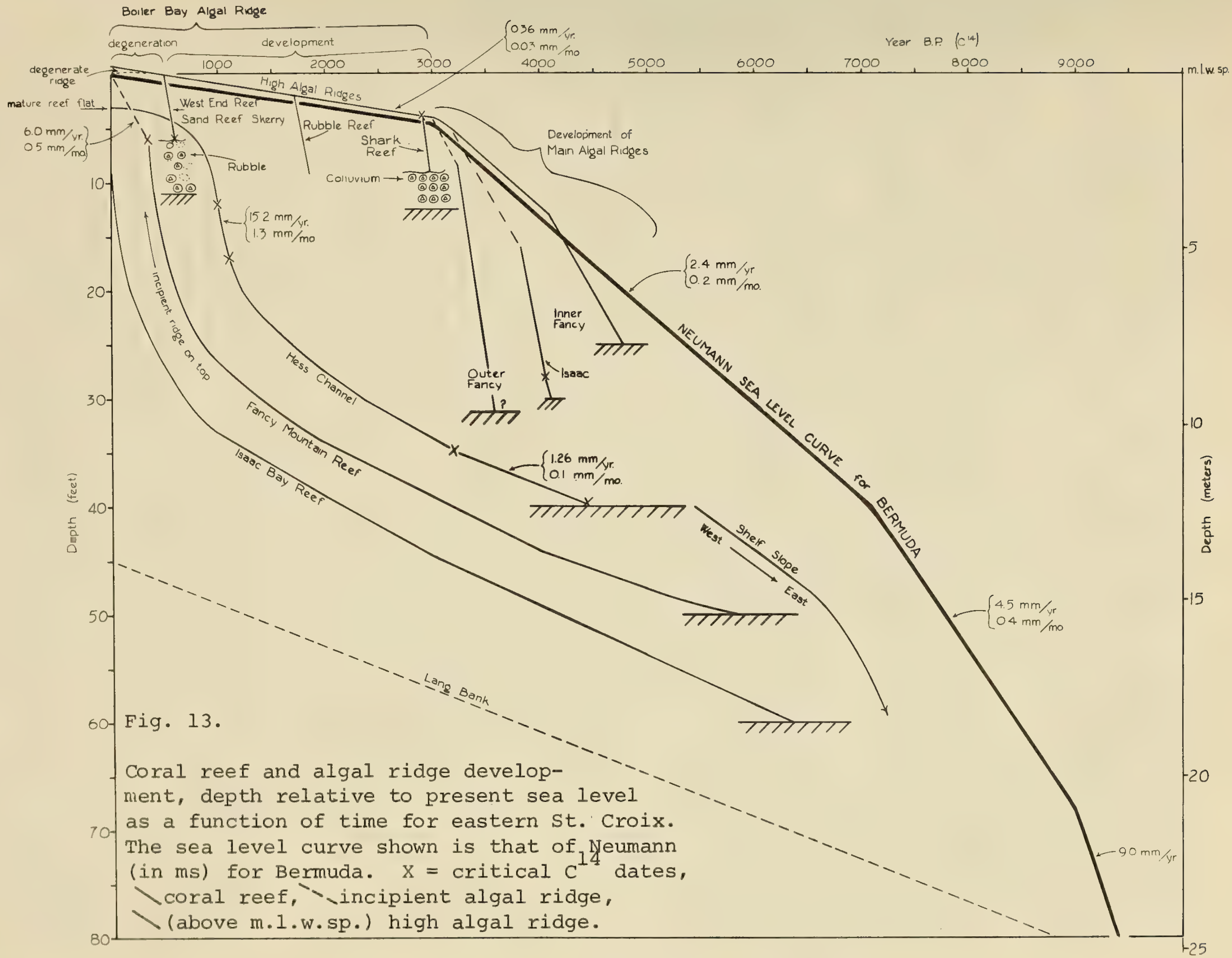


Fig. 13.

Coral reef and algal ridge development, depth relative to present sea level as a function of time for eastern St. Croix. The sea level curve shown is that of Neumann (in ms) for Bermuda. X = critical C^{14} dates, coral reef, incipient algal ridge, (above m.l.w.sp.) high algal ridge.

As discussed above, the inshore pre-Holocene shelf on southern and eastern St. Croix slopes irregularly eastward. Even allowing less time for reef establishment on these more easterly shores, but considering the more rapid rise of sea level prior to 7000 years B.P. at -12 meters, these reefs, at the same growth rates, would have been slower to reach the surface than those to the west. Thus, the general pattern of reef morphology, more mature to the west and less mature eastward.

Applying the same reasoning to the easternmost margin of the shelf and assuming no marginal pre-Holocene ridge, the shelf edge at about -25 meters would have been covered by a rapidly rising sea level at about 9500 years B.P. Taking the average depth of Lang Bank as about 45 feet and using a rate of 1.3 mm/year, the Bank could have been developed in its present proportions by beginning its Holocene reef growth within a few hundred years after being placed in the marine environment. This is in agreement with the conclusion reached by Macintyre (1972) that the submerged (or marginal shelf) reefs of the eastern Caribbean are Holocene (or latest Pleistocene). These relations also indicate that if sea level remains near its present level for another 4-5000 years that a shelf edge reef will form at Lang Bank, thereby depriving the inner reefs and ridges of wave action.

Adey and Burke (1975) have indicated that pre-Holocene shelf depth is one of the primary factors controlling reef presence and placement in the eastern Caribbean. Barrier reefs only occur where shelf depths are less than 25 meters and the most mature systems where shelf depths are less than 15 meters. When adversely comparing Pacific atoll reefs with those of the Caribbean, this should be borne in mind. For example (Lalou, et al., 1966) showed that the pre-Holocene topography under Mururoa reef islands was only at 6-10 meters, and Wiens (1962) cites fore-reef terrace depths of less than 20 meters for Bikini, Eniwetok, Rongelap, Zohhoiiyoro and Raroia. This suggests that perhaps major differences between Pacific and Caribbean reef development are not Holocene biological or climatic problems but Pleistocene geological problems, i.e., that the eastern Caribbean pre-Holocene shelves are relatively deep when compared to those of Pacific atolls.

Several patch reefs northeast of Buck Island rising from a sandy shelf at about 10 to 12 meters appear to be anastomosing thickets of massive *Acropora palmata* from bottom to top. Also, recently Macintyre and Glynn (1974) drilled an intertidal reef flat off Caribbean Panama and found up to 11 meters of *Acropora palmata* most of which accumulated from 6000 to 2000 years B.P. The top 0.5-3 meters of this reef was younger reef flat dominated by *Millepora*, *Agaricia agaricites*, *Porites furcata* and coralline algal accumulation. This indicates that given proper shelf depths, perhaps 5-15 meters, and favorable environmental conditions, that extensive growth of *A. palmata* can start shortly after submergence and develop reef structures dominantly of this coral.

ALGAL RIDGES

In turbulent areas open to the easterly trade wind sea, the uppermost Acropora palmata fore reef, at depths of 0 to -2 m, is frequently an irregular coralline-encrusted pavement (Fig. 11). Sometimes the original outline of the A. palmata is obvious and a broken branch will show a coralline accretion of a few mm to many cm on the dead coral. In other cases, even though a vague outline of the original A. palmata arms is still present, one can break off projection after projection and find only coralline. In many of these areas, e.g., off Fancy Mountain (Fig. 22), Robin Bay, western Jack Bay, Isaac Point (Fig. 19) and in Lamb Cove, just shoreward of these pavements, the A. palmata shapes gradually disappear to be replaced by an irregular coralline pavement which slopes up to about low water levels.

Several Neogoniolithon species are important on these pavements and Porolithon pachydermum is sometimes conspicuous. If the pavement extends to near low water levels, Lithophyllum congestum may be abundant, building small irregular heads extending above mean low water. Under overhangs, and in the abundant holes Lithothamnium ruptile, Mesophyllum syntrophicum and sometimes Archeolithothamnium dimotum along with Homotrema are also responsible for considerable carbonate accretion.

We have cored two of these coralline-A. palmata pavements or "incipient algal ridges" near their crests at about mean low water springs. During the first, at Jack Incipient Ridge, our drill transmission failed at 80 cm of nearly solid coralline crust with about 50% recovery. The upper part of the core is quite fresh in appearance. Further down, although crust corallines are still dominant, much boring, and re-fill of cavities by sediment and mineralization has altered the cores. The alteration and mineralization of these algal structures appears to be similar to that described for the Bermudian cup reefs by Ginsburg and Schroeder (1973), and I have not carried out a detailed examination of these processes in the Cruzan ridges. The incipient algal ridge drilled was on the outer reef south of Fancy Mountain (Fig. 22). Here we drilled through almost 2 meters of little-altered coralline, with a little Lithophyllum present, but mostly crust species with scattered Homotrema. Although occasionally the vermetid Dendropoma is important in these algal structures, incipient as well as high ridges, it is more often absent or a very minor element. This differs rather markedly from the Ginsburg and Schroeder (l.c.) description of the Bermudian cup reefs. From 2 to 3 meters in the Fancy incipient hole, with only about 10% recovery only coral was found. This was dominantly Acropora palmata although Diploria species and some Porites astreoides also occurred. Immediately below the coralline cap, a C^{14} date of 355 years B.P. was obtained in a large, clean core of A. palmata, thus providing an accretion rate in this incipient algal ridge of 5.6 mm/year. Adey and Vassar (1975) have studied crustose coralline accretion rates on plates in reef and ridge environments on St. Croix, finding values of up to 5.2 mm/year. They attribute high accretion rates in turbulent environments to reduced grazing action especially by parrot fish, and show that in quiet areas where these fish can operate effectively net coralline accretion can be reduced to 0.5 to 1 mm/year.

Once an incipient ridge builds to elevations near mean low water, branching Lithophyllum congestum often becomes dominant, as it has on some of the incipient knobs off Lamb Cove. Steneck and Adey (1975) have shown this plant to dominate highly in turbulent areas at $\pm$ 10 cm of m.l.w. springs and to achieve average branch tip growth rates of 8 mm/year and accretion rates of 4 mm/year. Within 10-15 cm of the surface of a Lithophyllum congestum head, the interstitial space between the branches is often filled with wave-driven sediment that is subsequently cemented by high magnesium calcite into a hammer-ringing hard limestone. Except around holes or channels, Lithophyllum congestum is replaced by Porolithon pachydermum at ridge elevations above about 20 cm above mean low water springs. In areas of especially high turbulence, the latter plant is capable of building the ridge to levels of about 50 cm above m.l.w.sp., i. e., about 20 cm above mean high water springs (see Fig. 2). (Adey and Burke (1975) have reported other algal ridges in the considerably rougher Martinique-Guadeloupe area that reach heights of one meter above m.l.w.sp., approximately the height of the higher Pacific atoll ridges.)

In the small, open cove just to the south of East Point, the irregular Acropora palmata pavement blocks at depths of 2 meters fuse into lobed coralline pavements that extend to elevations of up to about 30 cm above m.l.w.sp. These lobes, dominated by Lithophyllum congestum, with raised rims and weakly-developed bowls behind and separated by rubble channels 1-2 meters deep, have not developed extensive overhangs or interlobe fusions. Although we have no subsurface information on this small algal ridge, its surface configuration as compared to the well-developed ridges and the immaturity of the offlying A. palmata reef suggests that it is the youngest of the Cruzan ridges with a thickness of only 2-4 meters and has existed as a high ridge for only a few hundred years. Since this ridge provides an intermediate developmental stage between the incipient ridge condition now fairly abundant on the maturing A. palmata reefs at the eastern end of St. Croix and the older high algal ridges, it would be especially desirable to core it. It is quite rough however, and it would probably be necessary to construct a large, high platform from which the drilling could be undertaken.

I will begin the discussion of the major high algal ridges on St. Croix with the complex off Robin Point on the south shore (Figs. 14-17). This ridge lies on a southwesterly projection of the reef system. It is open to the easterly sea, almost perpendicular to the direction of the wave train and is generally the roughest and most active of the Cruzan ridges.

In the outer line, there are some small individual boilers or cup reefs from 2 to 3 m in diameter with well-developed raised rims all around and marked central depressions. Other boilers range up to about 30 m in diameter with the highly raised rims being present only on the seaward margins. In the latter case, the central basins are often either open on the back or with a slight rim, and are relatively deep, about 1 m, often with large Diploria heads. These larger ridge elements are formed by series of fused individual boilers (Fig. 15). The largest of these, platform reef transected by section AA', is about 120 m long and

averages about 40 m in width. In places, the junction between fused boilers is marked by the still raised rims and by a conspicuous slot occasionally wide enough for an arm or pole. In other places, there is little direct surface evidence of the fusion, except for the obvious inward curving of the two boilers where they meet marginally. However, underneath in this case, there is usually a quite open channel wide enough for a diver to swim through. Many of these outer ridge elements are honeycombed with such caverns, the rounded walls being coated with many layers of shade coralline species as well as Homotrema and Squamariacea.

The waters immediately around the high algal ridges often are relatively deep, 3-6 meters, and in addition to rubble and sand patches, in some of the channels, the pavements often support a community of Diploria spp., Millepora and Montastrea annularis. In this environment, these corals tend to be scattered but quite large. In the deeper area at 5-6 m in front of Robin Ridge, some Diploria colonies 1-2 m in diameter extend nearly to the surface.

We were able to drill three holes on Robin Algal Ridge, but none of these extended to the basement. The deepest of these, on the outer part of the high ridge on section AA, broke out into an underlying cavern at about 3.5 meters and was terminated. The core in this case was dominated by branched heads of Lithophyllum congestum to a depth of about 2 meters with crust species and abundant Homotrema below. Using the Neumann sea level curve (Fig. 13), this indicates that this ridge has been growing at or near mean sea level at least since 3300 years B.P. The remaining two Robin cores are short, 1 m, and were placed in the back ridge area on section AA'. The surface of this "ridge" is now about one m below m.l.w.sp. and has little coralline on its surface. Diadema antillarum is abundant and the pitted, scraped and gray carbonate surface is obviously being removed by grazing. However, below several cm, the cores are dominantly crustose coralline. This suggests that this structure was once a high ridge, perhaps older than the outer series, that was subsequently blocked from the required wave action by the development of the younger outer series. Shoreward of this second line, there is a third series of ridge-like structures which may also be degenerating high ridges.

Presently, seaward and southeast of Robin Ridge an active Acropora palmata reef is developing. This is shown on both figures 14 and 16. The surface of this reef is still 2-4 meters below sea level and only occasionally do waves break on it. However, it has likely already reduced some of the wave energy delivered to the ridge complex and is probably partly responsible for the degeneration of the back ridge system. If this reef has a growth rate comparable to that of Long Reef, a well-developed reef flat will have formed within 6-800 years and Robin Ridge will be in full degeneration.

Isaac Algal Ridge off Isaac Point is, in area, one of the smallest high algal ridges. However, being quite exposed, it has rim heights, about 50 cm above m.l.w.sp., equal to any known on Robin Ridge. There are a few off-lying individual boilers in the southwestern part of the

Fig. 14. Aerial photograph of Robin algal ridge. Compare with map (Fig. 16). Note A. palmata reef building everywhere seaward of the ridge except in the narrow sand channel (mid-right).

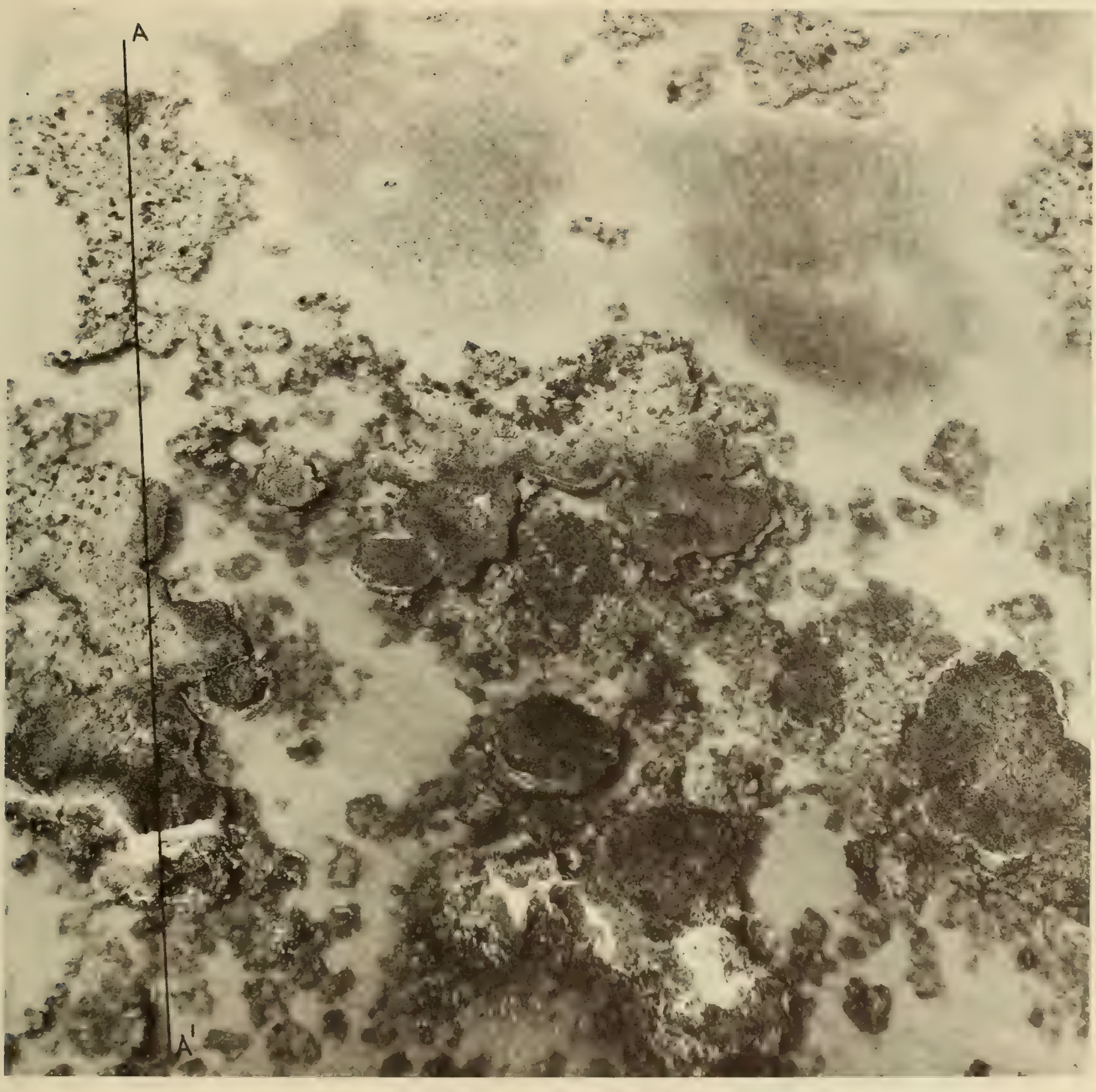


Fig. 15. Large scale aerial photo of the central section of Robin ridge. (See Fig. 16 for location of AA'.) The fused "boiler" origin of a large part of this ridge is evident here. See figure 17 for depths.

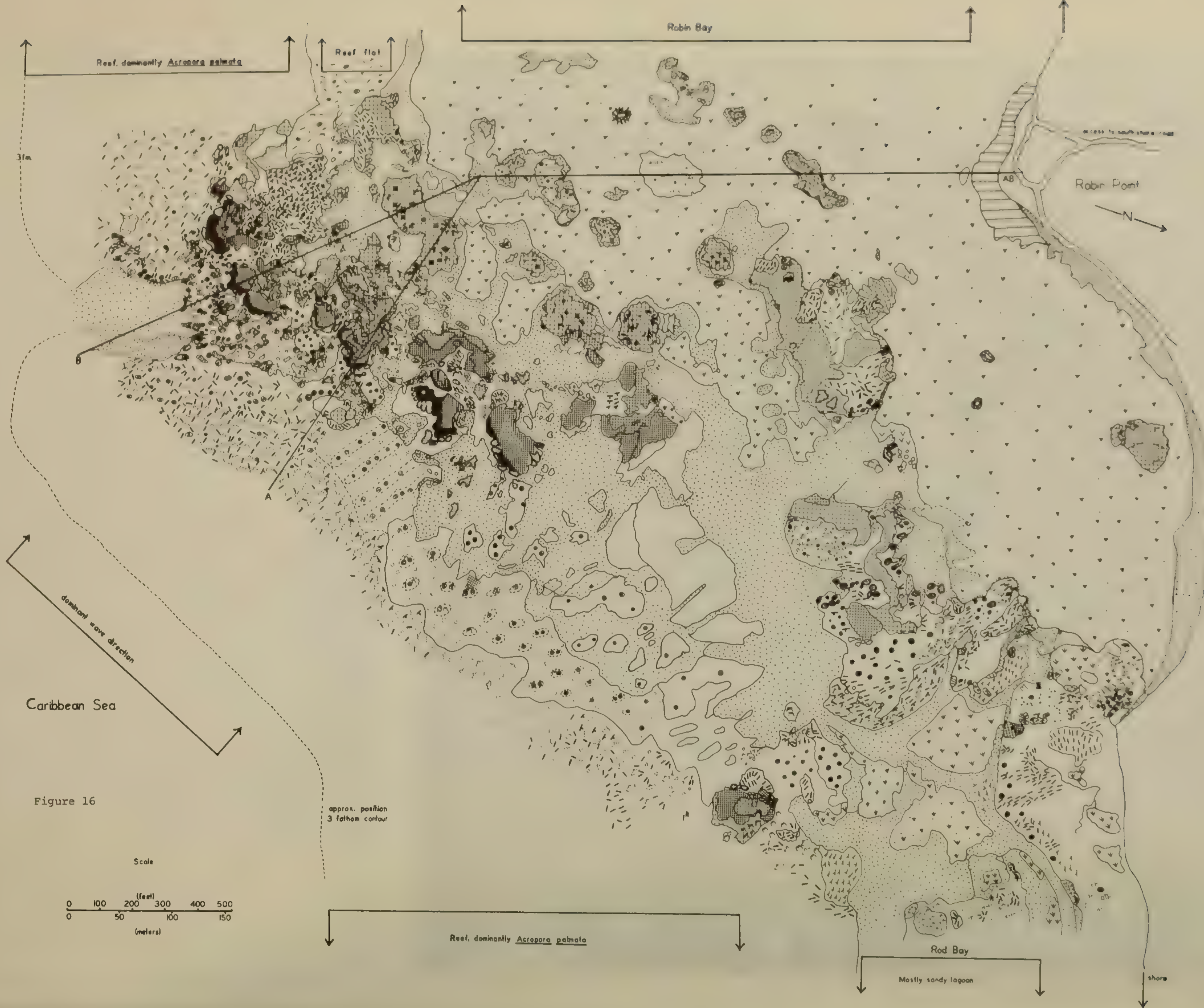

Reef, dominantly Acropora palmata
Reef flat
Robin Bay
Robin Point
N
AB
3 fm
B
A
dominant wave direction
Caribbean Sea
approx. position
3 fathom contour
Scale
0 100 200 300 400 500
(feet)
0 50 100 150
(meters)
Reef, dominantly Acropora palmata
Rod Bay
Mostly sandy lagoon
shore

Figure 16

Fig. 16. Robin algal ridge complex and the surrounding coral communities. Indicated sections are shown in Figure 16. Ridge elevations relative to m.l.w.sp.: +15 to +50 cm, -10 to +15 cm, -100 to -10 cm, -200 to -100 cm. The following symbols are used on all of maps below:

living Acropora palmata
dead standing

rubble

pavement

living Diploria spp.
dead

living Montastrea annularis

living Millepora
dead

living Porites porites
dead or Porites pavement

living Acropora cervicornis
dead
pavement

Siderastrea siderea

Porites astreoides
dead

collapsed blocks of algal ridge

Caledonia bedrock

sand

beach rock

dominantly Thallassia grass

dominantly Syringodium grass

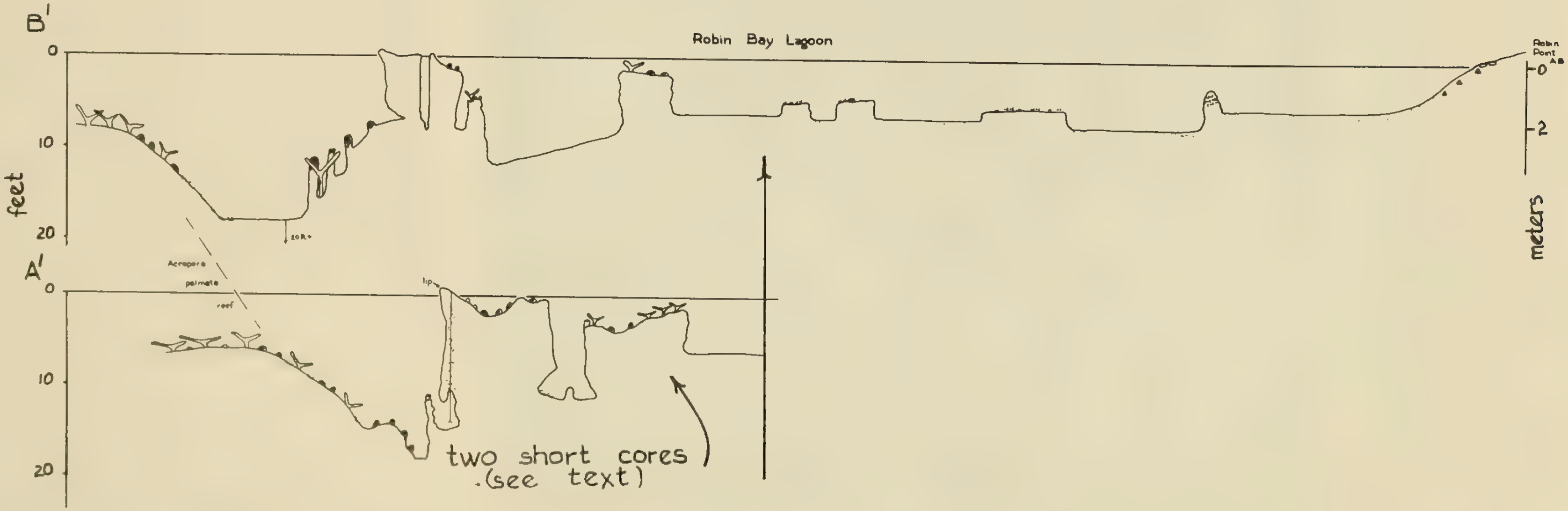


Fig. 17. Sections of Robin algal ridge complex shown in figures 14-16.

ridge system, and in the eastern corner only a partial fusion of several boilers has taken place (Figs. 18, 19). These have the typical high, fleshy algae covered rims, the uppermost sections being relatively smoothly encrusted with Porolithon pachydermum and the front or lower areas dominated by Lithophyllum congestum. The higher parts of rim and fore-ridge areas have few Echinometra and tend to be relatively smooth. However, the upper back ridge areas at approximately -20 to +20 cm are heavily infested with these echinoids and their burrows, making walking very difficult. The elongate main section of the ridge has developed by a fusion of boilers. This is quite apparent in the eastern section where one can still swim through some of the channels below. However, in the central and western sections, the only obvious evidence for the original boiler structure is the presence of scattered closed caves at least one of which extends back to the ridge "flat" as a very narrow slot. The result of boiler fusion over a long tract has been the exclusion of wave action from the back ridge areas, and a pronounced narrowing of the high ridge zone. The back ridge "flat" is now at about -1 m and is dominated by Porites porites and Porites astreoides.

It should be pointed out here that while the Pacific atoll algal reef margins are called ridges, they are more or less formed of boilers as described here. This is well shown by the massive, boiler built ridge system described for Muroroa by Chevalier et al. (1968) and as diagrammed by Emery, Tracey and Ladd (1954) in their classic treatment of the Bikini ridges.

The southeast corner of Isaac Ridge has a quite low rim, and the collapsed blocks just to the outside have apparently broken out of this position. On the eastern corner of this area, an unfused boiler has fallen over, with the upper surface now resting at about 45°. The upper portions of this conspicuous tilted boiler now project nearly a meter above low water and have the characteristic pitted surface of coastal subaerial eroding limestone (see Fig. 18). Just outside of this tilted block, a new boiler is developing, having reached the incipient stage just below m.l.w.sp. This incipient boiler can be traced seaward into the Acropora palmata pavement on which it is developing.

A single core hole has been placed in one of the eastern lobes of Isaac Ridge. The dominant elements encountered are shown in figure 21. At about 8 meters, a mixture of Caledonia and coral fragments were encountered which made drilling virtually impossible with our rig. I have interpreted this as a Caledonia bedrock surface, but it has not been established with certainty that it is not a weathered, Pleistocene reef surface with terrigenous pebbles and cobbles. A sand probe to the outside of the ridge, as shown, did not reach a hard surface at 15 meters, thus indicating that the basal structure of the algal ridge is formed on a raised bench structure at 9 meters, at least 6 meters and probably 8-10 meters above the offlying shelf. A date of 4040 years B.P. was obtained from a large, clean core of Acropora palmata taken a foot or two above the basement. Unfortunately, this hole was not placed on a major ridge lobe, but rather on a minor lobe connecting two boilers. Thus, only 2.5 meters of coralline, mostly L. congestum, was encountered here, and from 3.5-6 meters a single massive Diploria head, of the type

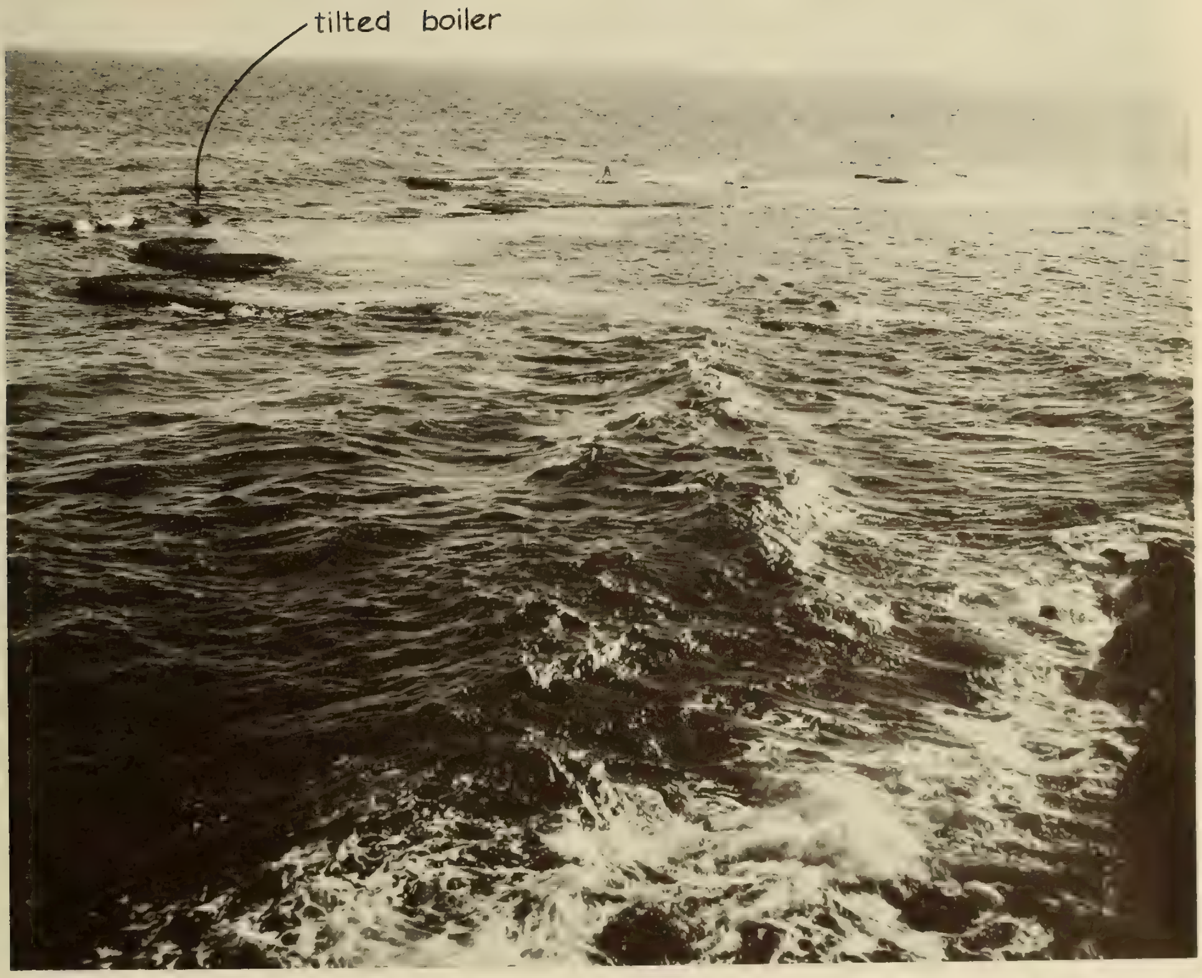


Fig. 18. Photograph of Isaac Algal Ridge on a relatively quiet day with a tide level of about +20 cm. Note figure standing (bent over) near the center.

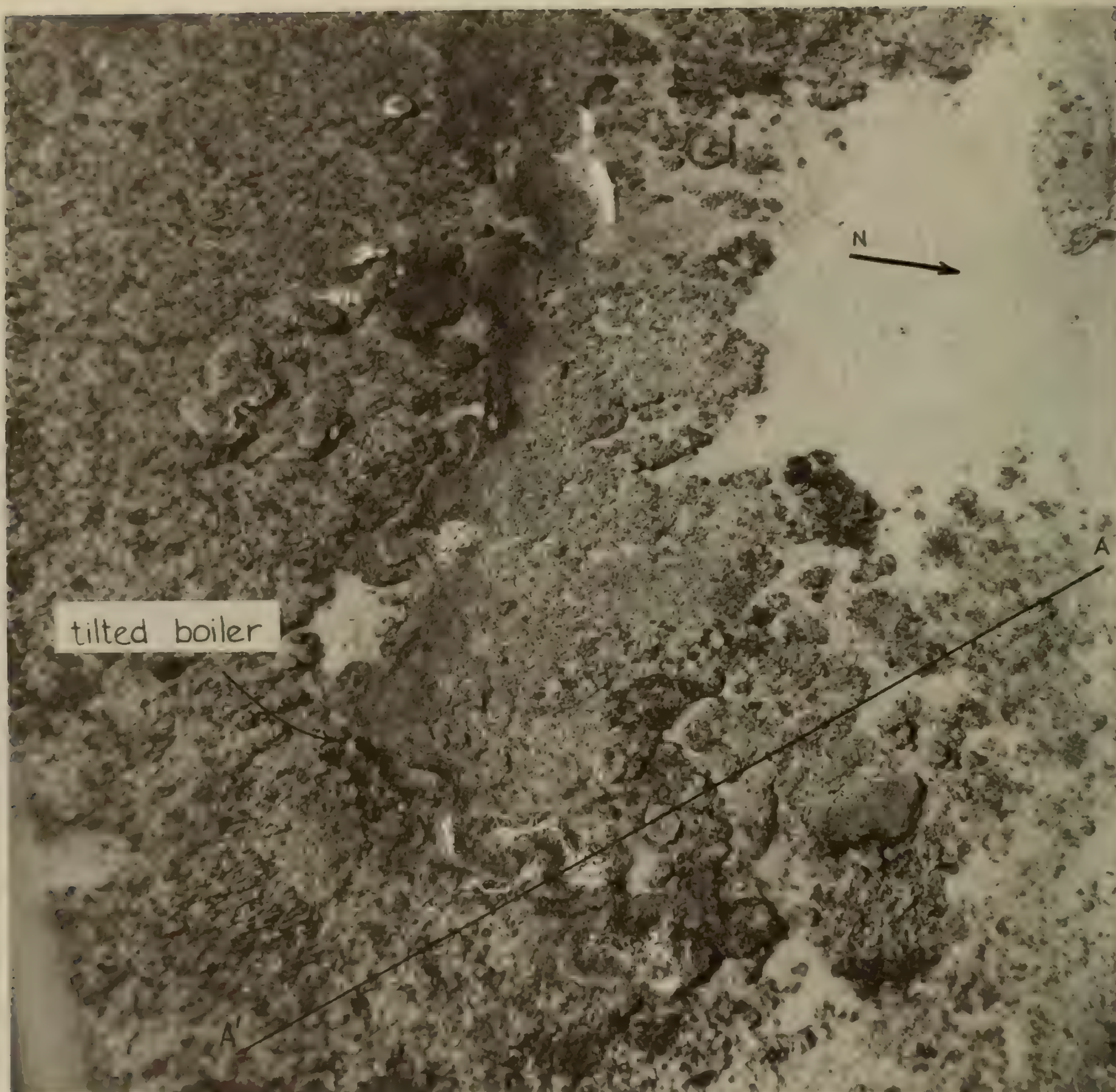


Fig. 19. Aerial photo of Isaac Algal Ridge taken at about 600 feet on an extremely quiet day. See figure 20 for scale.

Fig. 20.

Isaac Algal Ridge and surrounding coral communities. [black symbol] +25 to +50 cm, [dense grid symbol] 0 to +25 cm, [open grid symbol] -30 to 0 cm. Symbols as given for figure 16. (△) Caledonia pebbles and cobbles.

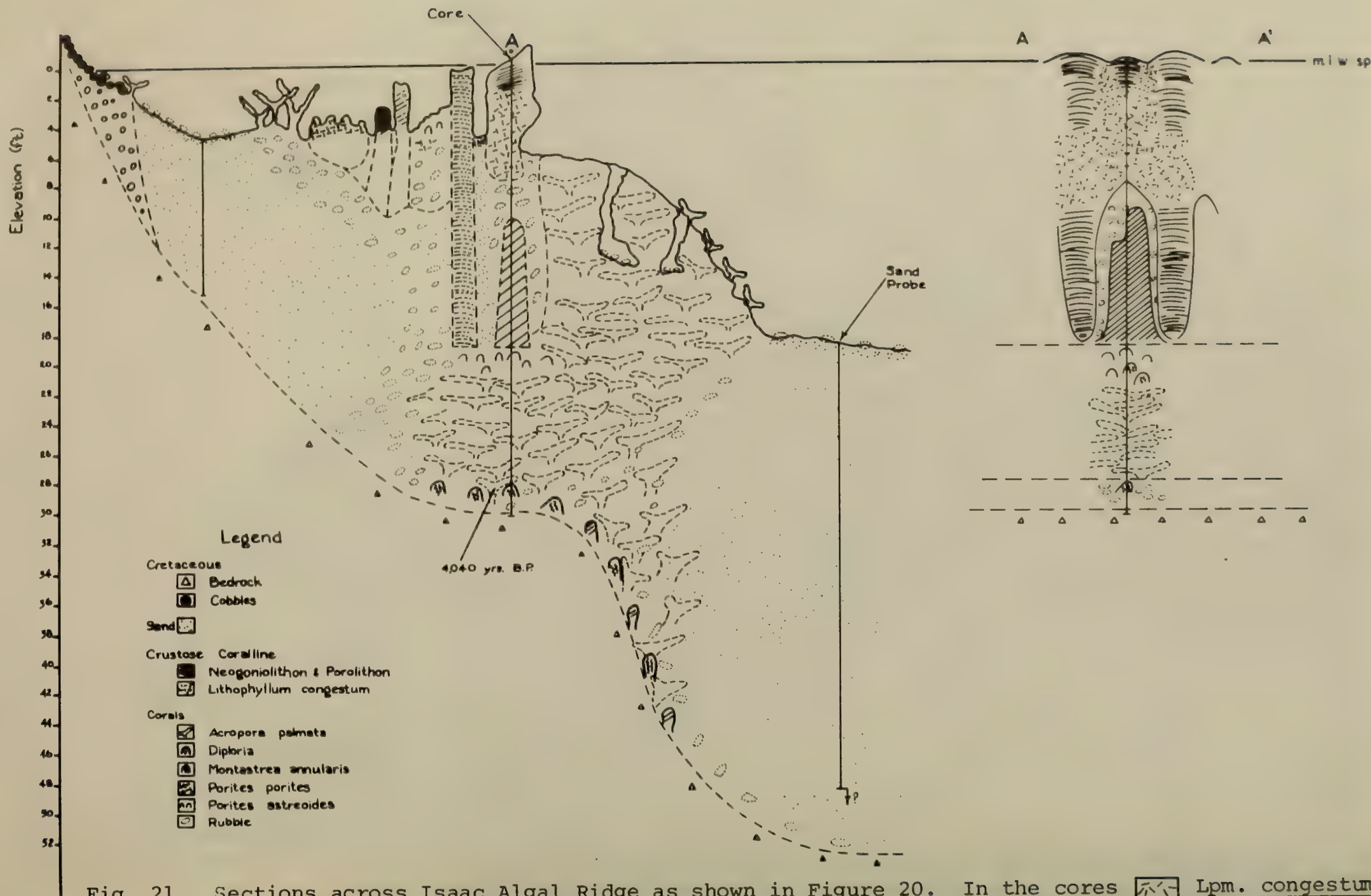


Fig. 21. Sections across Isaac Algal Ridge as shown in Figure 20. In the cores Lpm. congestum, crust corallines, coral rubble. The section AA' is an interpretation based on the surface characteristics of the boilers making up this section of the reef.

normally encountered in deeper inter-boiler channels, was cored. Below 6.5 meters, the sub-ridge structure was dominantly A. palmata. Based on the surface plan of the ridge in this area, an interpretive section parallel to the ridge front (AA') is also shown in figure 21.

The depth-age relationships of Isaac Ridge are shown in figure 13 and interpreted as follows: Sea level rose over the raised beach off Isaac Point at about 5700 years B.P. About 1600 years was required to establish strong reef growth on this bench. Since sea level was only about 5 meters above the bench in the eastern area, Acropora palmata dominated and quickly built the reef to within 1.5 to 2 meters of sea level. There, crust type corallines built the ridge to sea level, as an incipient ridge, by about 3200 years B.P. (determined by position of Lithophyllum congestum in the core). From that time until about 1300 years B.P., the ridge was dominated by L. congestum in the area cored and probably had a height of 0-25 cm above m.l.w.sp. The last part of the ridge section consists of coralline crust species, indicating that since about 1300 years B.P., this part of the ridge has maintained its present height.

The developing A. palmata reef off Isaac Algal Ridge is still relatively deep, 3-4 meters, although directly to the east off Isaac Bay a section of reef is approaching the surface. Probably it will be more than 1000 years yet before Isaac ridge will be blocked to the point of serious degeneration.

Figures 22 and 23 show the algal ridge pair and its associated incipient ridges off Fancy Mountain. These ridges are both relatively low and degenerating due to wave-blocking by the A. palmata reef forming outside. The inner ridge being partly blocked by the outer ridge reaches maximum heights of only +26 cm above m.l.w.sp. having an average elevation of +10 to +17 cm. The outer ridge averages +17 to +23 cm.

The core hole in the inner ridge returned a clean, 8 cm section of Caledonia with parallel top and bottom fracture planes at 8 meters. The boring then broke into coral rubble and jammed with hard drilling at 9 meters. I have interpreted this as shown in figure 23. While here also the piece of Caledonia could have been a cobble on a weathered reef surface, there is no evidence of a rounded nature on either end of the core and bedrock seems the most likely interpretation. The crust coralline in the core begins at 6 meters, and L. congestum at 4 meters, indicating that the coral reef structure developed on the ledge shown at about 4800 years B.P. had become an incipient ridge by 4500 years B.P. and finally a high ridge by 4300 B.P. (Fig. 13).

The core in the outer ridge is dominated by L. congestum only in the upper 1.5 meters and becomes mixed with Millepora and then Montastrea at 2.5 meters. Thus, the outer ridge is considerably younger than the inner, starting at about 3000 years B.P. Its position in line with the present Acropora palmata reef crest and in the vicinity of a number of presently-forming incipient ridges suggests the presence of a secondary bench or series of benches, in elevation somewhere between the high bench with the inner ridge at 8 meters and the outer shelf at approximately 15 meters.

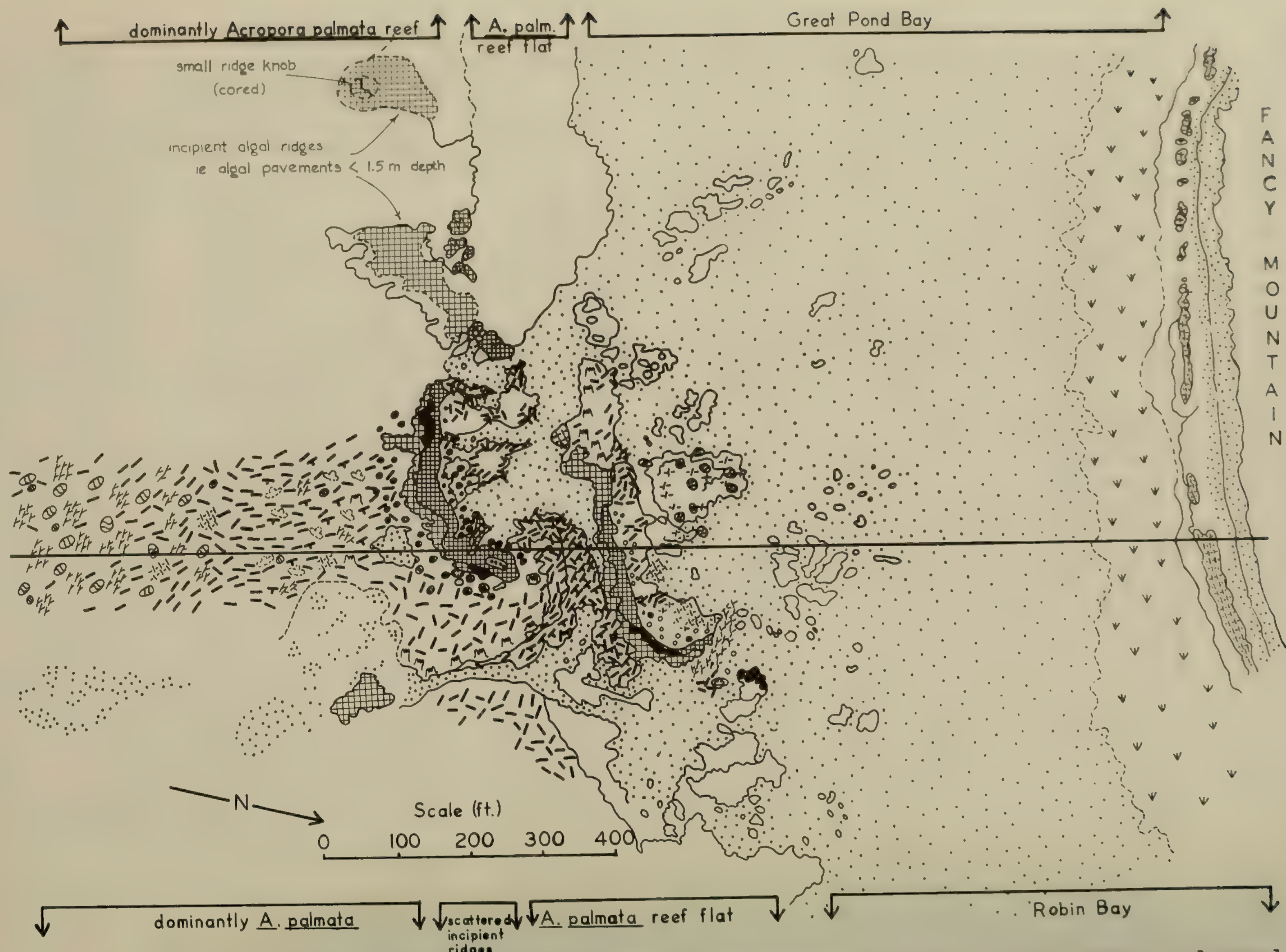


Fig. 22. Map of Fancy Mountain algal ridge pair and its associated incipient algal ridges and coral reef communities. Section shown in figure 23. ■ +15 to +30 cm above m.l.w.sp., ▦ -10 to +15 cm, ▦ -100 to -10 cm.

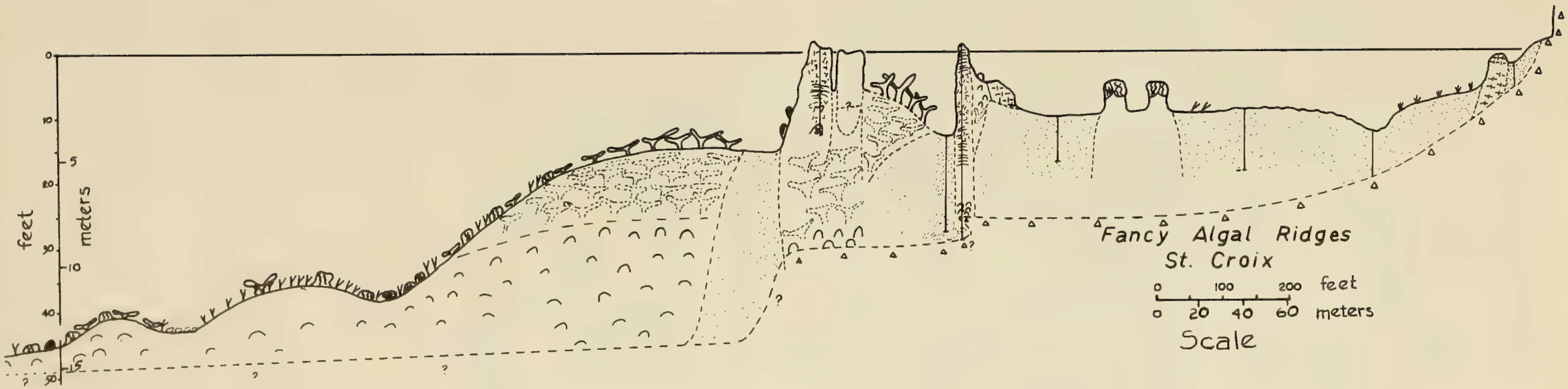


Fig. 23. Section from shore at Fancy Mountain, across Fancy algal ridges to the outer shelf. Symbols as previous figures. [symbol] inferred head corals Diploria spp. and Montastrea annularis.

Beach Algal Ridge, between Grassy and Grapetree Points (Figs. 24-27) is the longest (over 0.5 km) and straightest ridge on St. Croix. Although some narrow caverns are present extending back into the ridge, there is little surface evidence of boiler amalgamation. It is probably the oldest Holocene ridge on eastern St. Croix, 5000 years or more, although we do not have a core to establish this. Beach Ridge is not high, the maximum elevation measured being 22 cm above m.l.w.sp., and it is also being blocked by an off-lying reef system. In the eastern part of the area the off-lying reef has already developed a reef flat and to the westward it gradually decreases in height. The algal ridge behind is inversely proportional in its height to that of the reef. Behind the reef flat areas, it has degenerated to subtidal levels.

Beach Algal Ridge apparently lies on a bench that is greater than about 8 meters in depth, but probably considerably less than the shelf depth here of about 19 meters. Unless reef growth was particularly favorable at this locale, which doesn't seem likely because of its embayed nature, the maximum bench depth would be 10-12 meters. This inferred bench is conspicuously aligned with an inferred fault scarp on the island (see Fig. 27). Beach Ridge also grades into an *A. palmata-Millepora* rich reef to the west. This could result from a sloping of the underlying bench to the west to merge with the shelf. The sand channel in front of Beach Ridge is quite deep and abrupt. It is mostly 8 to 10 meters in depth, but reaches 13 meters in its western sections. It is bigger and much better defined than any of other fore ridge channels known on St. Croix, perhaps because of the association with a pronounced scarp structure.

BOILER BAY ALGAL RIDGE

At the time of our arrival on St. Croix in mid-1972, the boilers or "cup reefs" of Boiler Bay were generally known to the considerable number of scientists who had worked on the eastern end of the island. The high algal ridges, although easily visible from the air, had not been noted, as they can be quite obscure to the swimmer especially with average wave conditions and without low water spring tides. Perhaps it is unfortunate that our work was begun in Boiler Bay, as this ridge is certainly the most atypical on the island. Some of the 32 holes drilled in Boiler Bay could perhaps have been more useful on the larger ridges.

Except for East Point algal ridge, the Boiler Bay ridge is the only one associated with the head of a bay. The former case does not even appear as much of an exception as the cove is quite shallow and faces due east. Most of the other algal ridges are associated with points, or in the case of Beach ridge an apparent fault scarp oriented almost normal to the wave train. Most of the high ridges are also associated with the point-forming East End Member of the Caledonia Formation suggesting development on benches cut at 10 to 12 meters, perhaps at the 30 to 40 thousand B.P high level sea stand.

The central boilers of the Boiler Bay ridge are resting on a 0.5 to 1.5 meter thick lag colluvial deposit (Fig. 28). The latter, a weakly

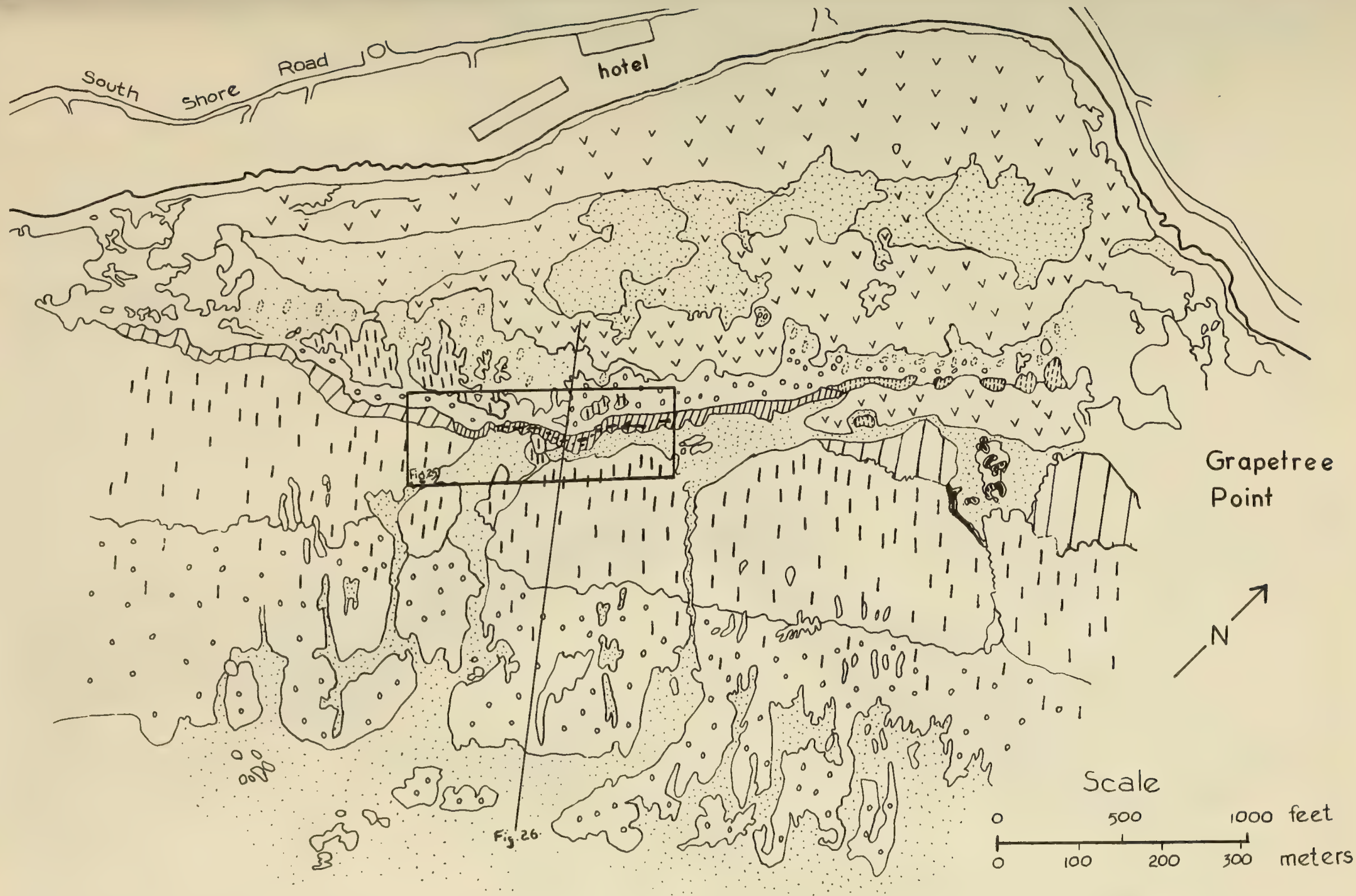


Fig. 24. Coral Reef and algal ridge complex between Grassy Point and Grapetree Point. high algal ridge, reef flat, algal ridge area, Acropora palmata fore reef, Diploria-Montastrea deep fore reef and back ridge, sand, grass. Section shown in figure 26.

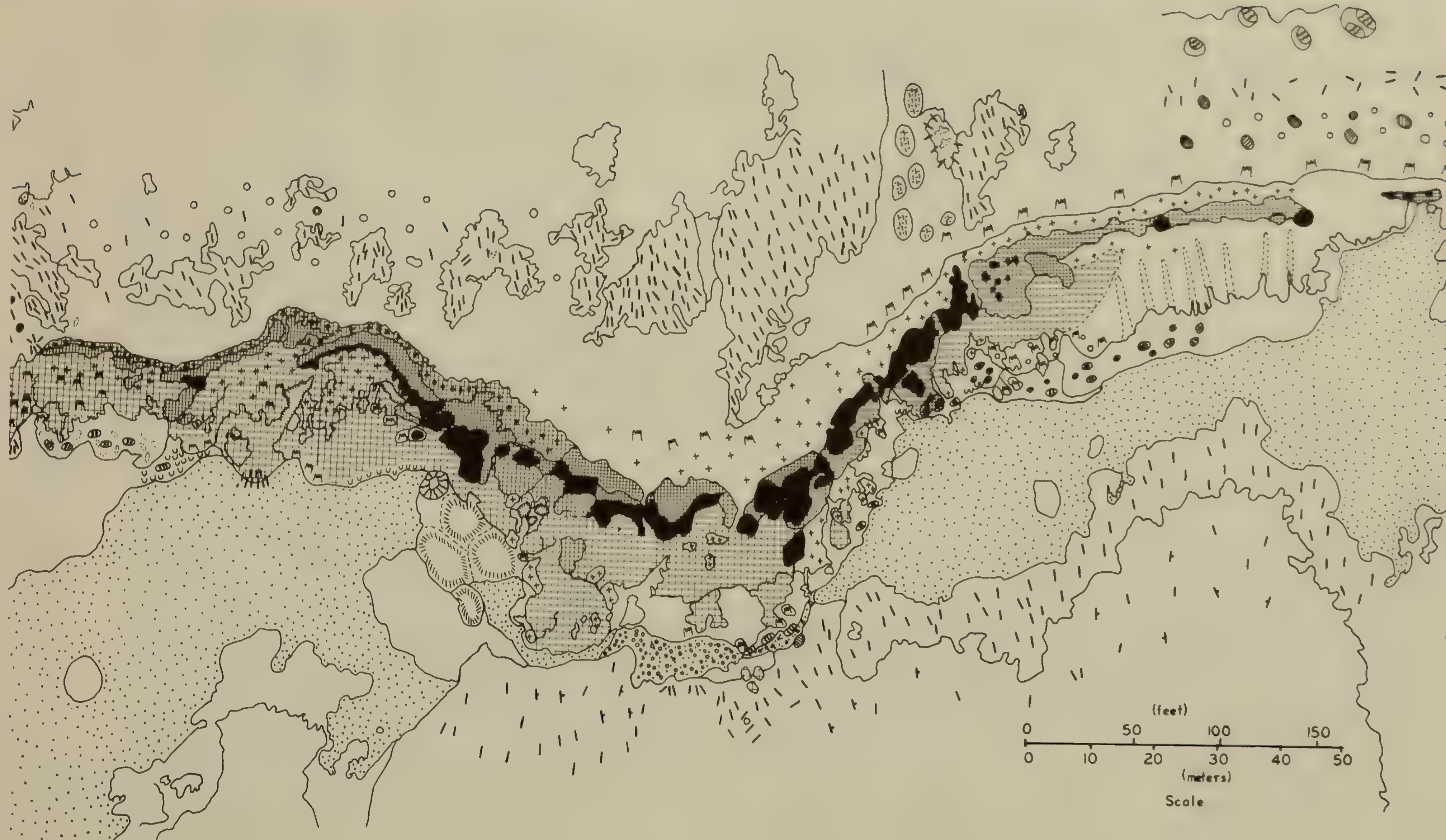


Fig. 25. Beach Algal Ridge, area in inset of Fig. 24. ■ 0 to +22 cm above m.l.w.sp., ▦ -20 to 0 cm, ▦ -100 to -20 cm, ▦ -300 to -50 cm. Otherwise symbols as previous diagrams.

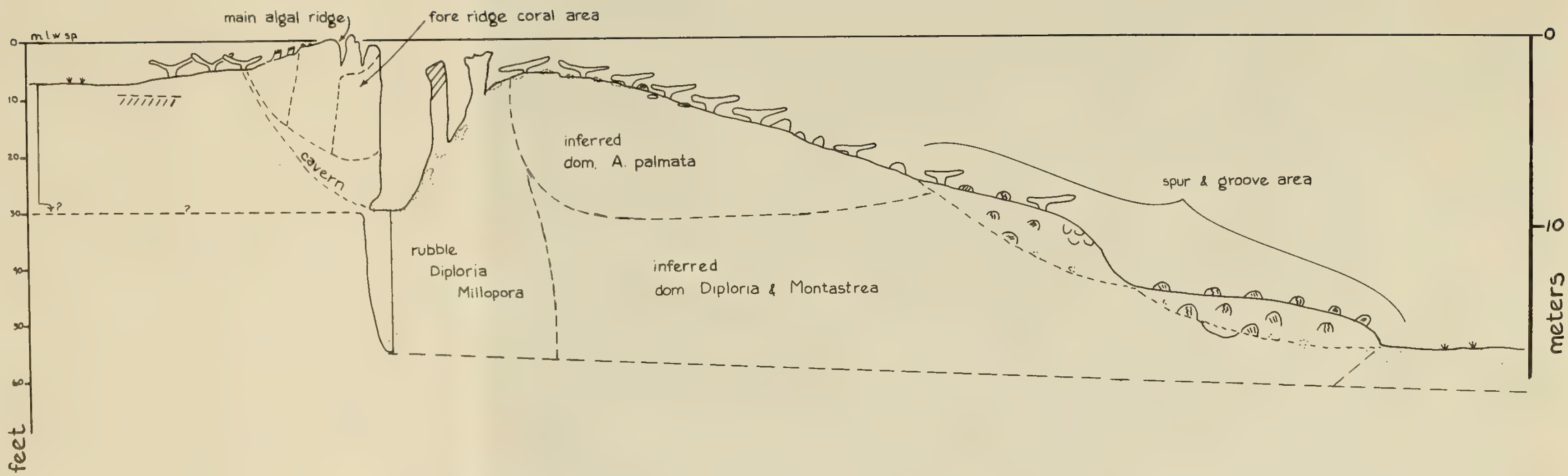


Fig. 26. Section of Beach Algal Ridge and off-lying reef complex as shown in figure 24.

Fig. 27. Aerial photograph of Beach Algal Ridge area showing apparent continuity of inferred bench beneath ridge with inferred fault scarp on land.

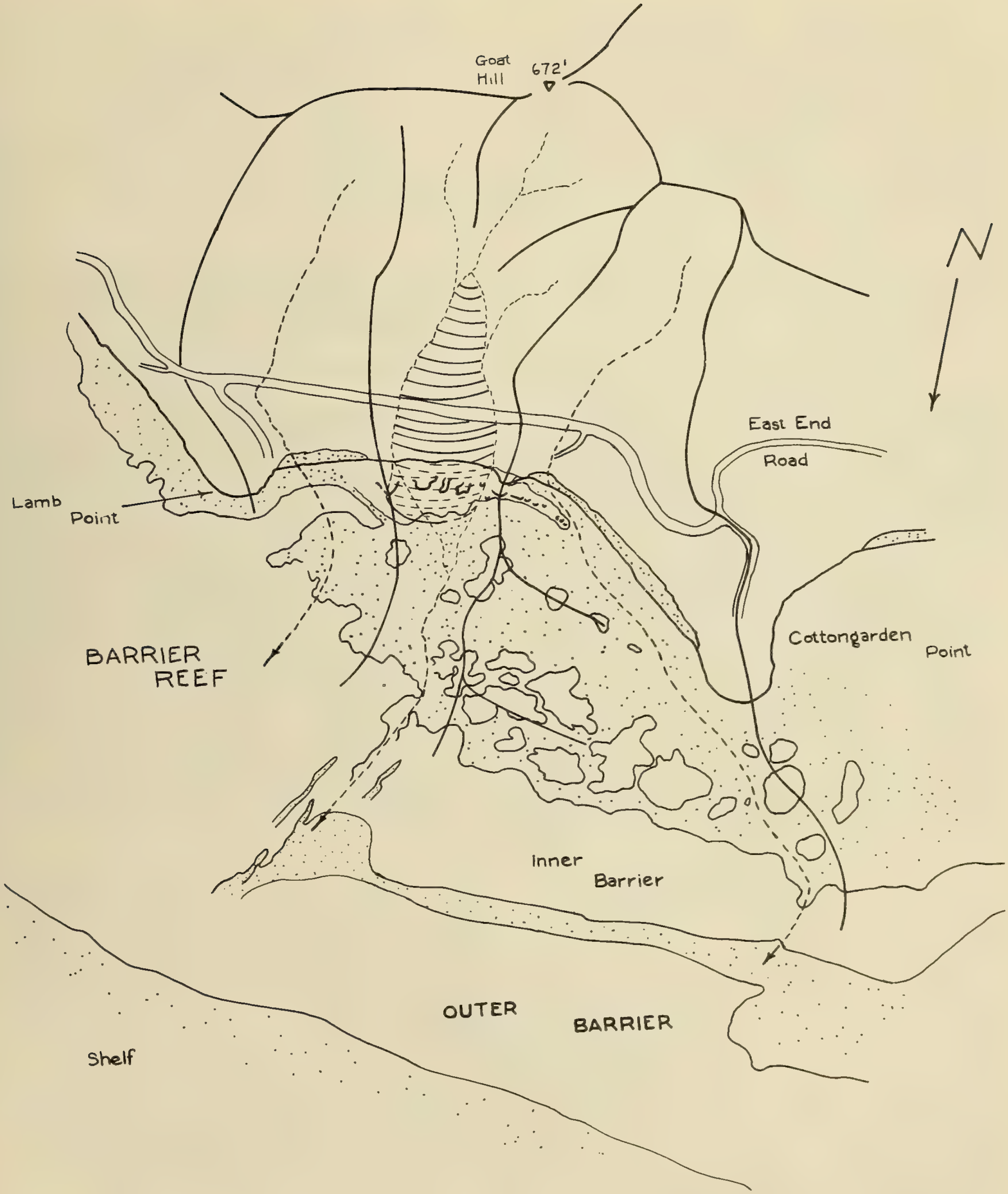


Fig. 28. Boiler Bay area (see Fig. 4) showing ridge crests and drainage patterns , colluvial lobe and offlying barrier reefs.

cemented probably Wisconsin rapid flow or colluvium consists of unsorted, angular Caledonia boulders, cobbles and pebbles in a silt-sand matrix. With late Holocene rise of sea level, this deposit was eroded rapidly, leaving a lag of boulders and cobbles, and now appears as a 10 meter high bluff, with a wave cut terrace behind the central ridge area. The boilers are stretched out across this boulder-pebble lag terrace between the two Caledonian ridges with a smaller set tailing out to the west probably on a pebble spit developed from the colluvium.

Details of the boiler-ridge area and the surrounding coral communities are shown in figures 29-37. Depths and subsurface data are given in figures 39-44, keyed as to locality in figure 38.

The surfaces and even the highest boiler rims in Boiler Bay are presently infested with Echinometra, their burrows occupying about 30% or more of the surface. Crustose corallines only occupy about 30% of the remaining surface, being intermixed with algal-bored, dead coralline, peyssonnelid crusts, Homotrema and the crusts or filamentous bases of the abundant fleshy-leafy algae. The latter develop a large and diverse standing crop and are discussed in detail by Connor and Adey (1975). The crustose corallines that are present are dominantly Neogoniolithon species, Porolithon pachydermum not being common and Lithophyllum congestum being quite rare. Tenarea bermudense, a shade species, can be a massive accreter on the undersides of overhanging lips. Even though wave action is presently insufficient in Boiler Bay to sustain effective growth of L. congestum, the borings at Shark Reef slot show that this plant was the major constructor of these ridges (Fig. 40) just as it was on the present high ridges. Adey and Vassar (1975) have shown that present coralline accretion rates on the crests of these ridges are reduced to 1-2 mm/year. This is apparently not sufficient to maintain the ridges in the face of the massive Echinometra boring.

Long, overhanging lips appear to be more characteristic of the foreridge in Boiler Bay than the larger ridges, perhaps because reduced wave strength allow them to reach larger size. In addition to overgrowing and fusing with each other, boilers apparently fuse with Millepora heads and (Figs. 39 and 40) probably occasionally A. palmata colonies. Most of the boilers in Boiler Bay are based on A. palmata and some, e.g., Rubble Reef and Sand Reef Skerry (Fig. 44), have coralline caps only 0.4-1 meter thick (dominantly of L. congestum) making them less than 2000 years old (see figure 11). A few of the drilled boilers were found to be based on Millepora, mostly those in the far west areas. A C^{14} date on coral under West End Reef at 2 meters gave 650 years B.P. However, Millepora appears to frequently lack the strength to support a boiler alone and several "exploded" Millepora-based boilers occur in the area (see Fig. 34). A single boiler was found with an apparent Diploria base (Fig. 43A).

In large areas around the Boiler Bay ridges a relatively bare pavement occurred at depths of 1-4 meters. These have only scattered corals, usually Siderastrea siderea and Porites astreoides and are named according to the dominant coral. Crustose corallines are relatively unimportant on these pavements occupying in some cases as much as 30%, but usually less than 10-15% of the surface. Several Neogoniolithon species,

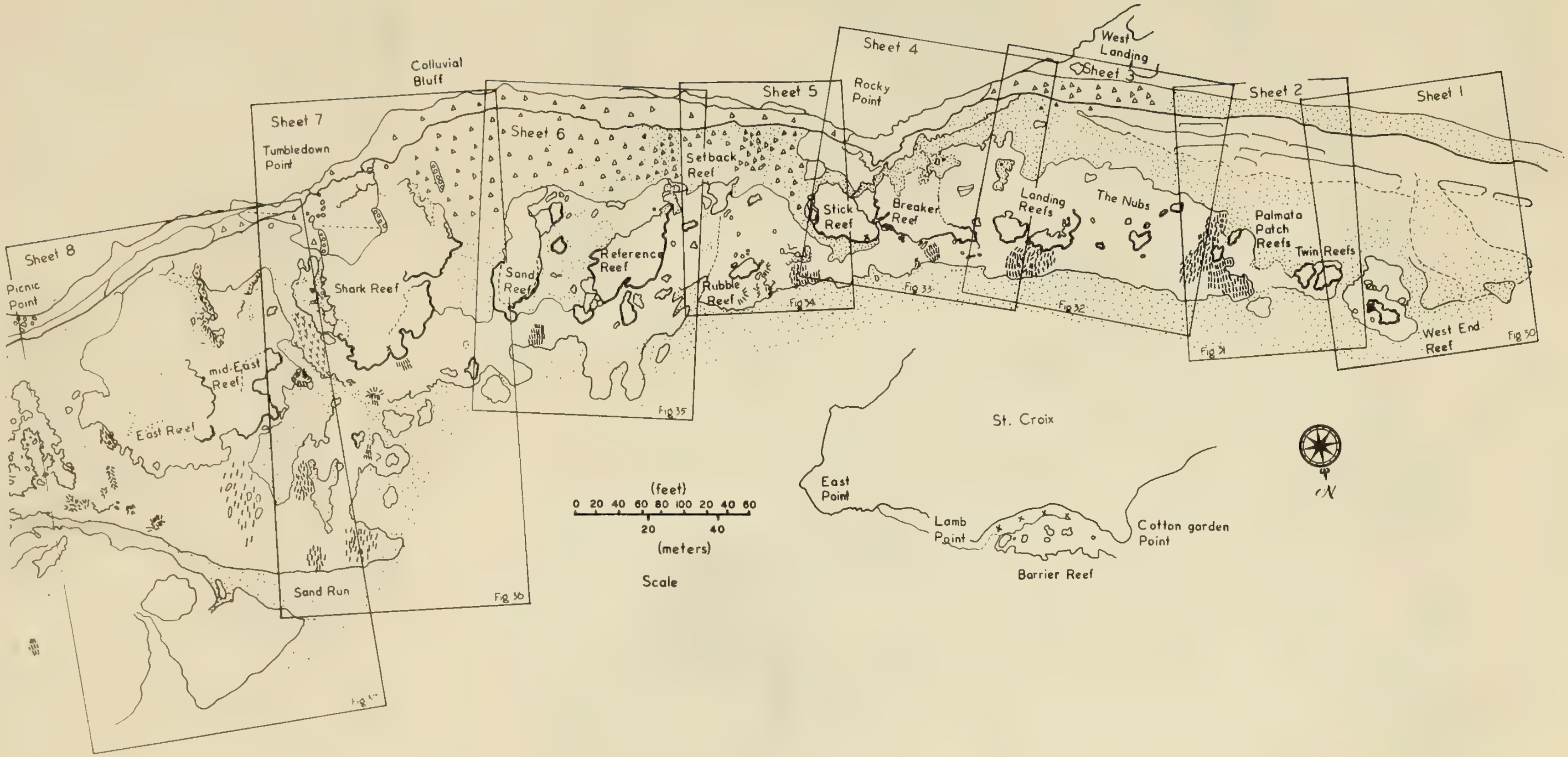


Fig. 29. Key map of boiler area of Boiler Bay showing the locations of large scale maps.

Fig. 30. Westernmost boiler, West End Reef. Algal ridge ▬ 0 to +17 cm above m.l.w.sp., ▦ -30 to 0 cm, ▦ -60 to -30 cm, ◻ pavement > 60 cm. Symbols otherwise as preceding maps. X rhodoliths (coralline nodules), △ terrigenous pebbles. See figure 42C for depths.

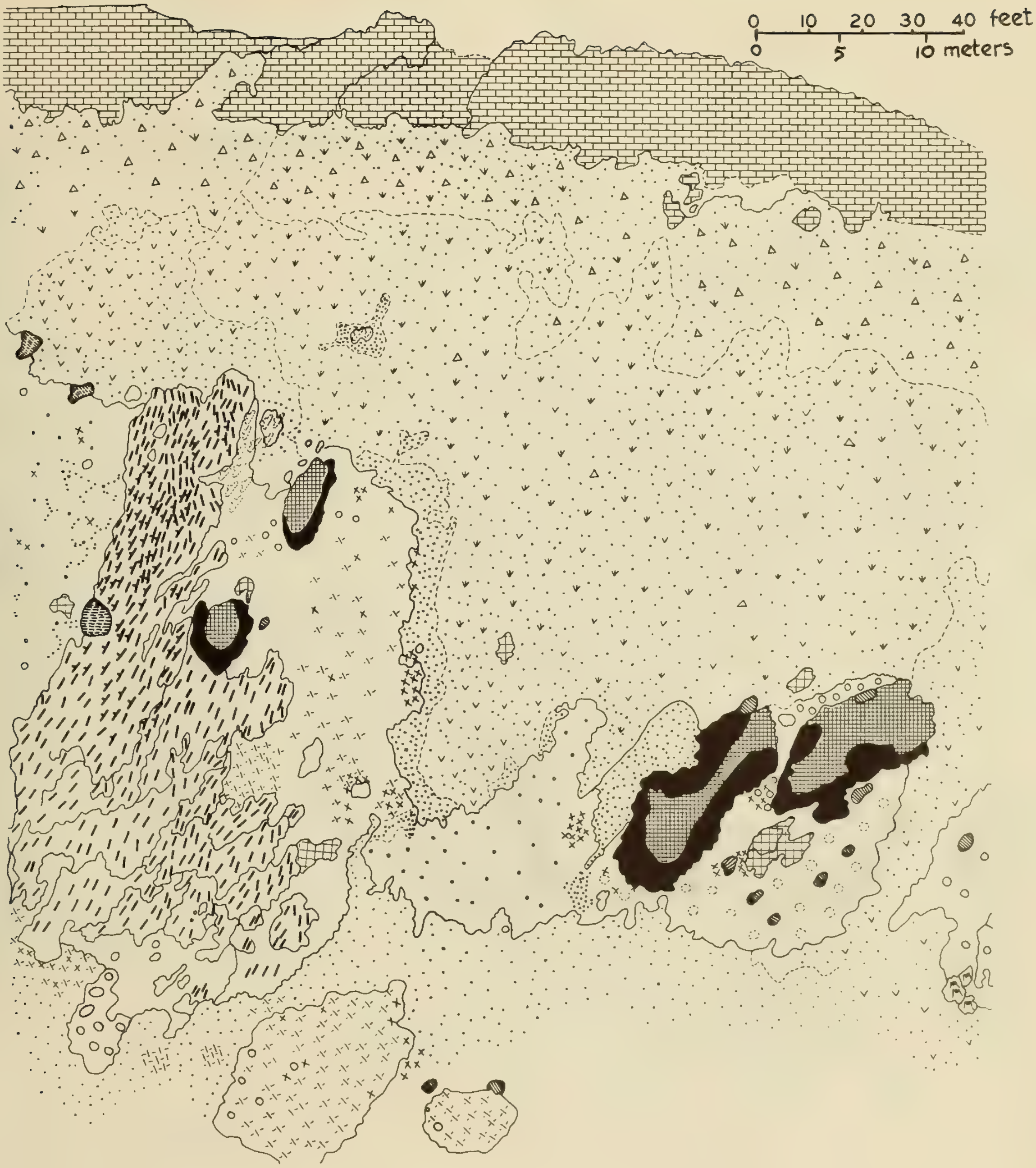


Fig. 31. Twin Reef and palmata patch boilers. The Acropora palmata patch is the largest presently live area of A. palmata in the boiler-pavement area. See figure 43B for depths.

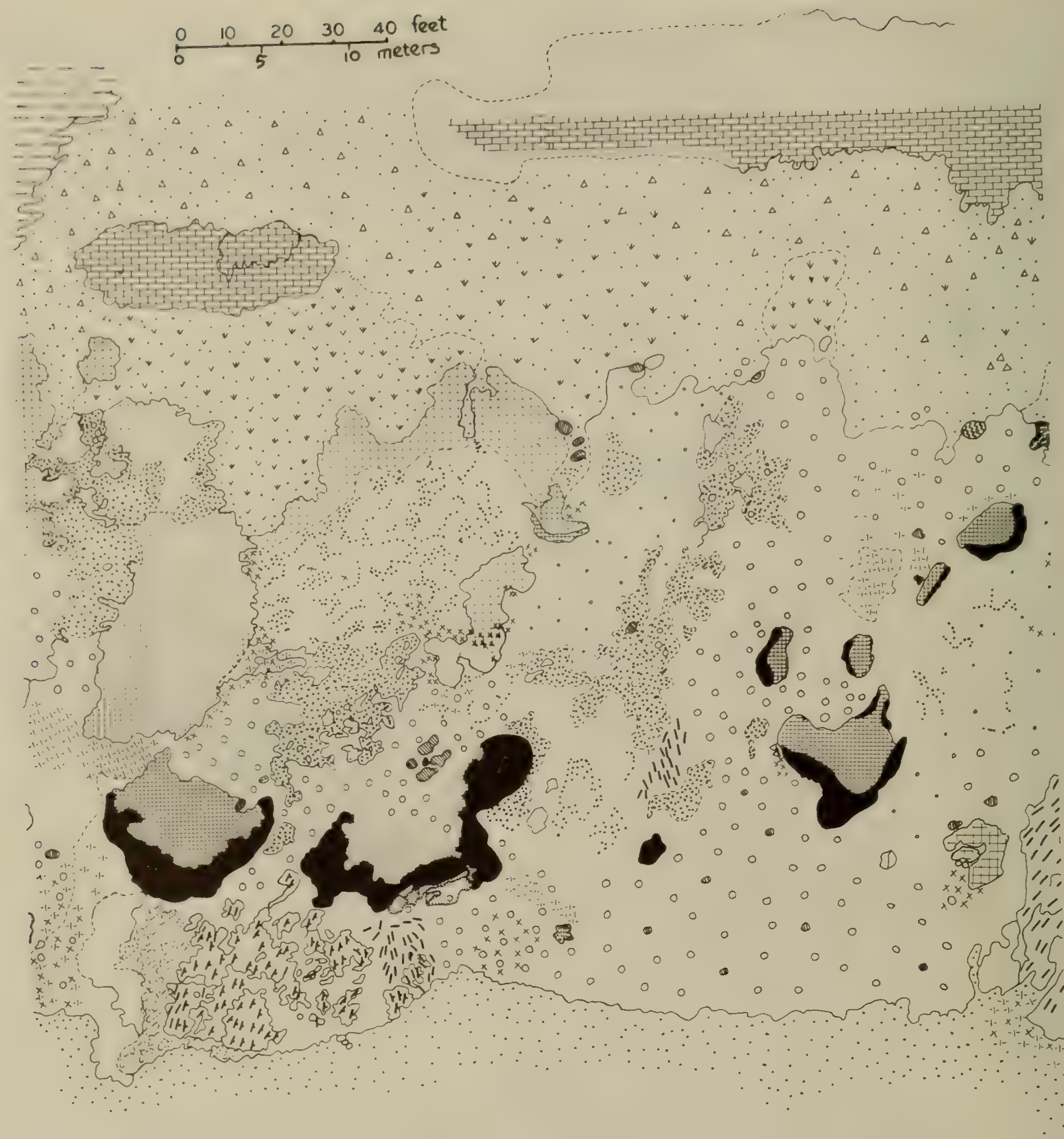


Fig. 32. Landing Reef and Nub boilers. See figures 43B & C for depths.

Fig. 33. Stick Reef and Breaker Reef. These are boiler-fused ridges, Stick Reef having some caverns, but the original boiler pattern is not obvious. Considerable collapse has occurred on the front of Breaker. See figure 41 for depths.

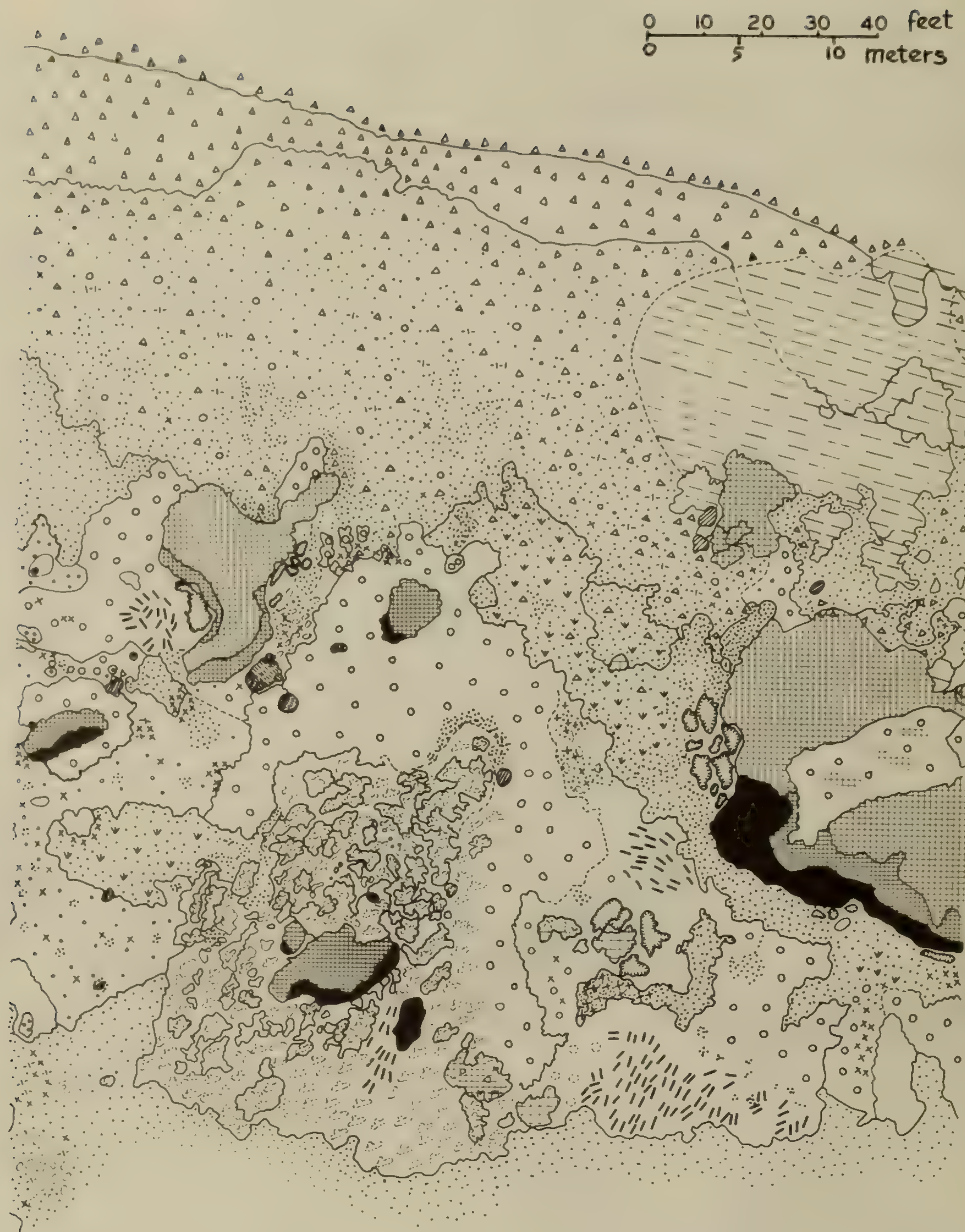


Fig. 34. Rubble and Setback Reef areas. Rubble reef is a young boiler developed on a massive recent A. palmata pavement. Halfway between Rubble and Stick is a Millepore-based boiler that has collapsed in a ring of broken blocks. See figure 44B for depths.

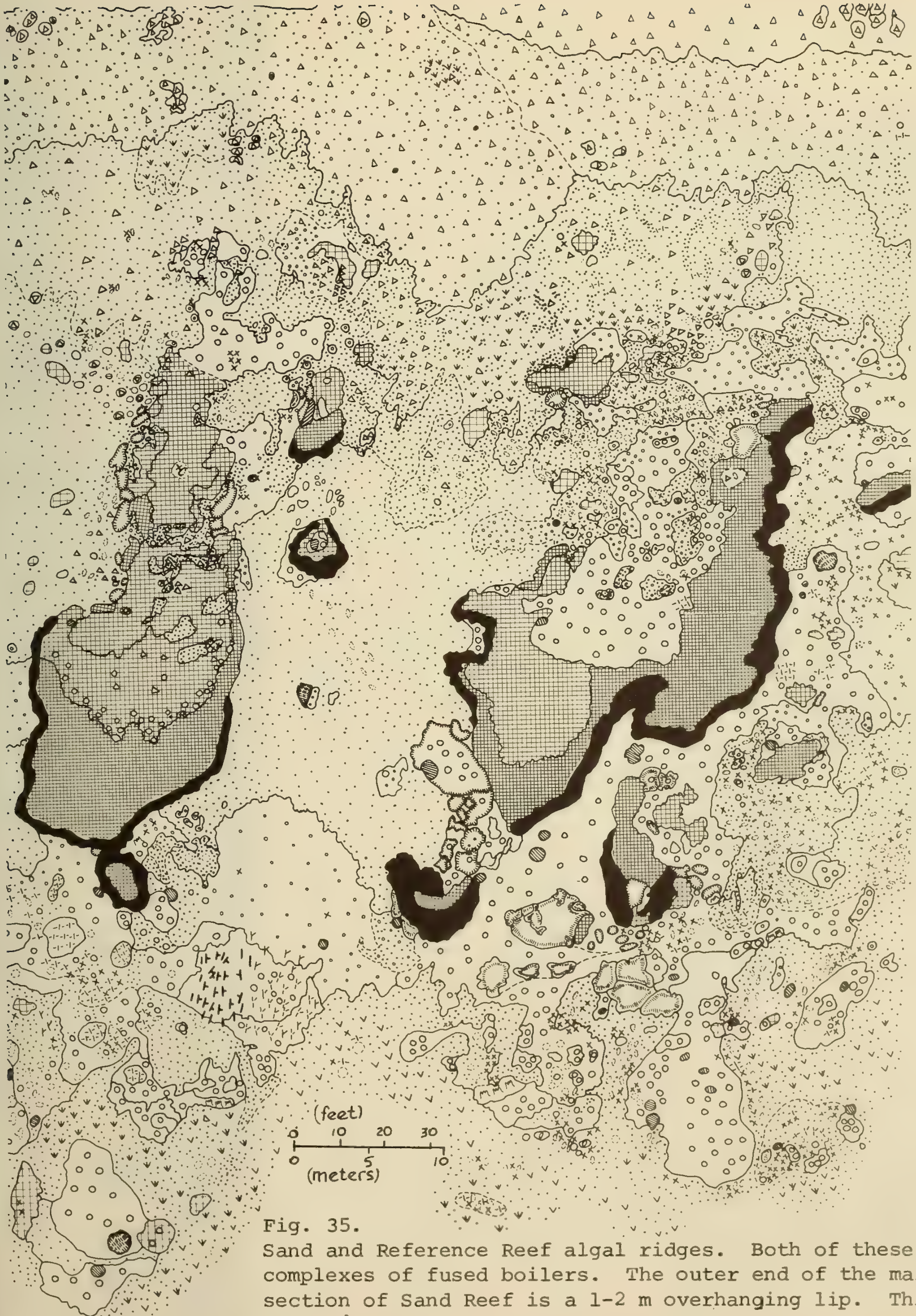


Fig. 35.
Sand and Reference Reef algal ridges. Both of these are complexes of fused boilers. The outer end of the main section of Sand Reef is a 1-2 m overhanging lip. This joins the small offlying boiler to form a short tunnel. Considerable roof collapse has occurred on the outer part of Reference Reef. For depths see Fig. 42B.

Fig. 37. East Reefs. This partly fused complex of boilers began to degenerate before completion of ridge formation. For depths see figure 42A.

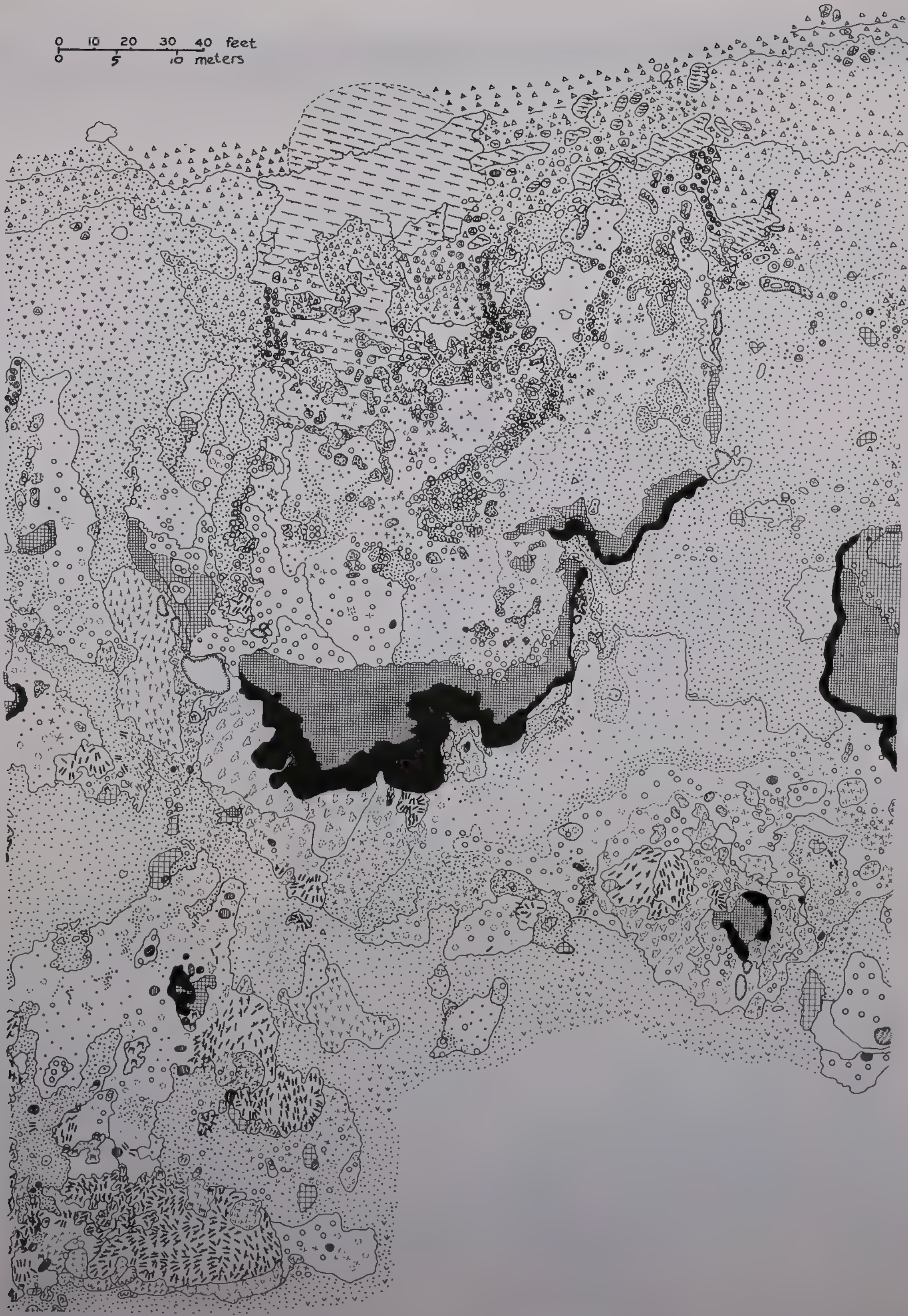


Fig. 36. Shark Reef. The largest and highest (17 cm) of the Boiler Bay ridges. A large cave occurs shoreward of the collapsed block at the east end of the reef. Sand Reef Skerry, offshore of Sand Reef is an A. palmata patch with a 30-60 cm cap of coralline. For depths see figures 39 & 43A.

0 10 20 30 40 feet
0 5 10 meters

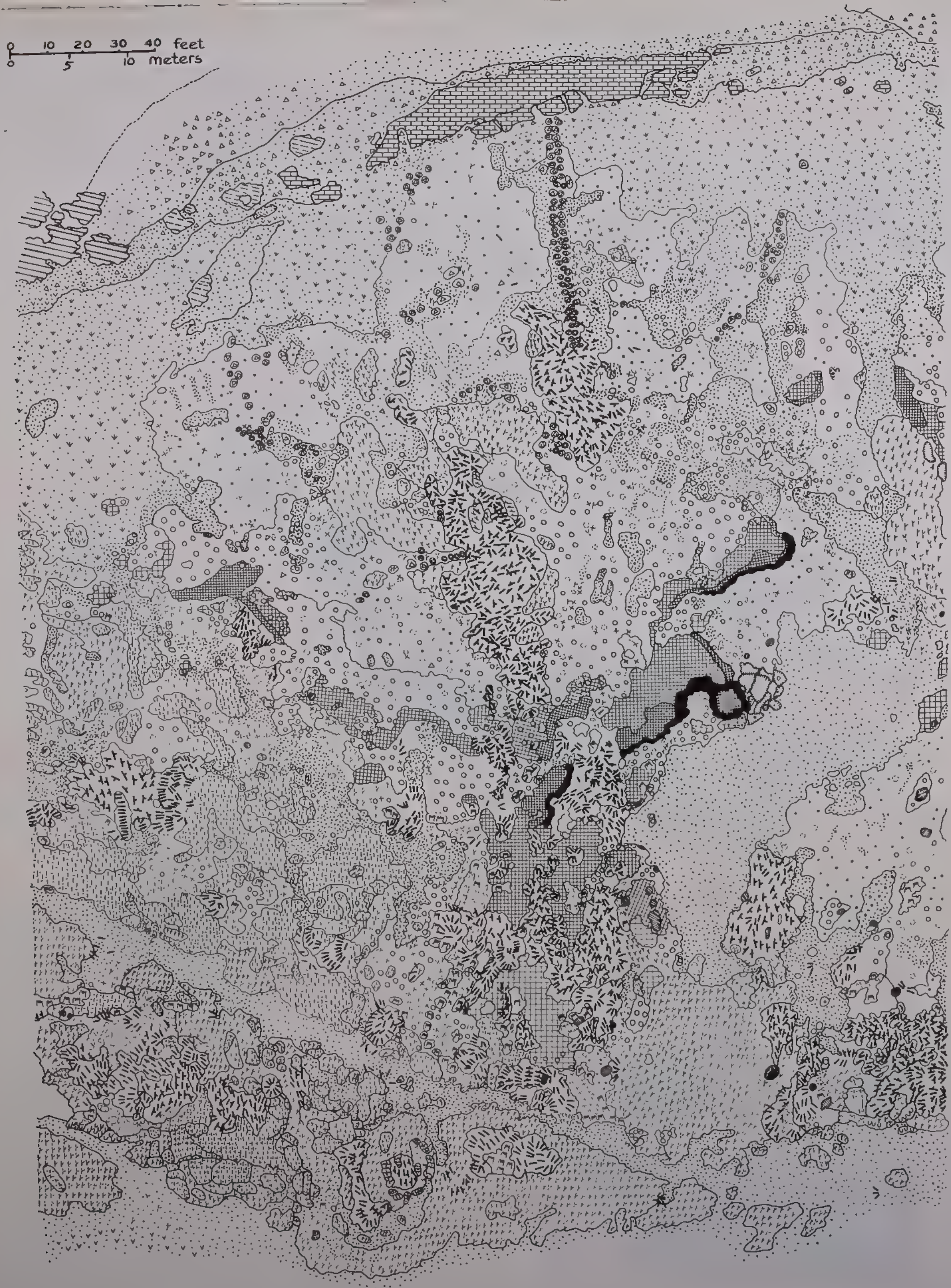


Fig. 37. East Reefs. This partly fused complex of boilers began to degenerate before completion of ridge formation. For depths see figure 42A.

Fig. 38

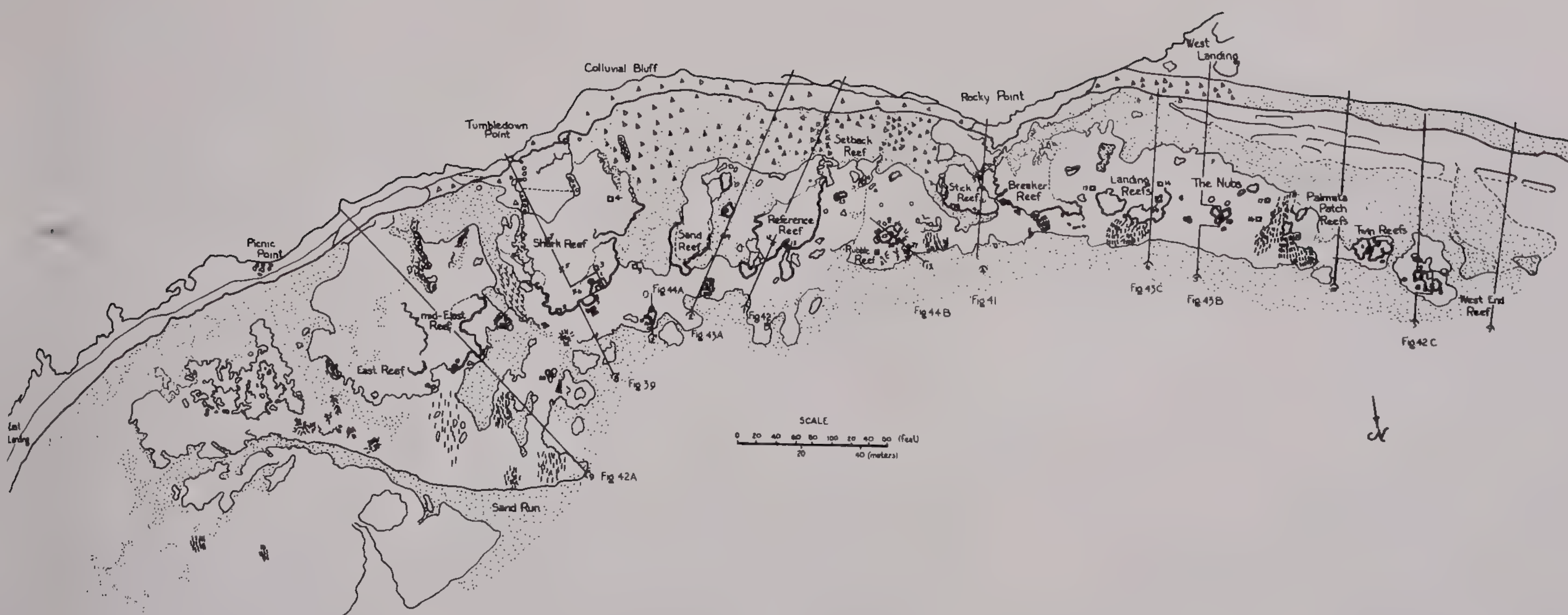


Fig. 38. Locations of transects, drill cores and collected ridge or pavement blocks in Boiler Bay. Transect 1 - Fig. 42B, Transect 2 - Fig. 43A, Transect 3 - Fig. 42C, Transect 4 - Fig. 41, Transect 5 - Fig. 43B, Transect 6 - Fig. 43C, Transect 8 - Fig. 39, Transect 9 - Fig. 42A, Transect 12 - Fig. 44A, Transect 13 - Fig. 44B.

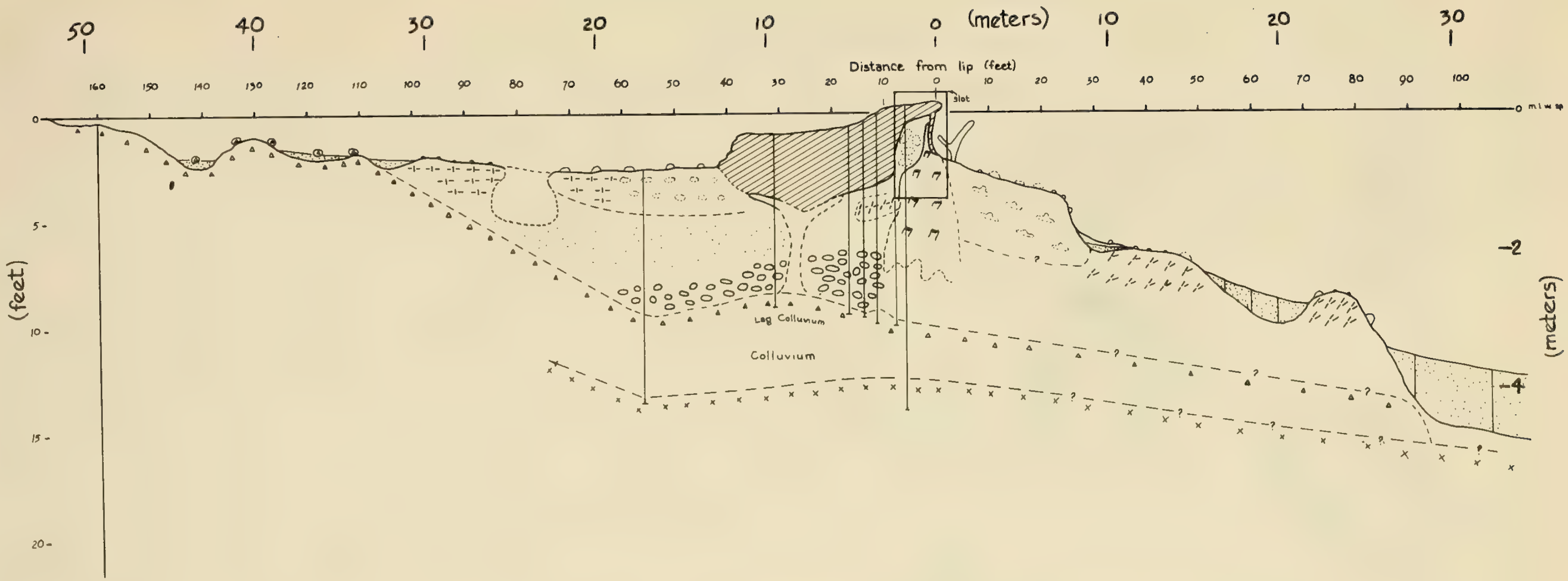


Fig. 39. Section through Shark Reef algal ridge. The details of the nose area are based on a 60 cm wide slot chiseled out of the ridge front (Fig. 40). The A. palmata immediately underlying the coralline cap was dated at 2900 years B.P. (see Fig. 13). ▨ crustose coralline cap.

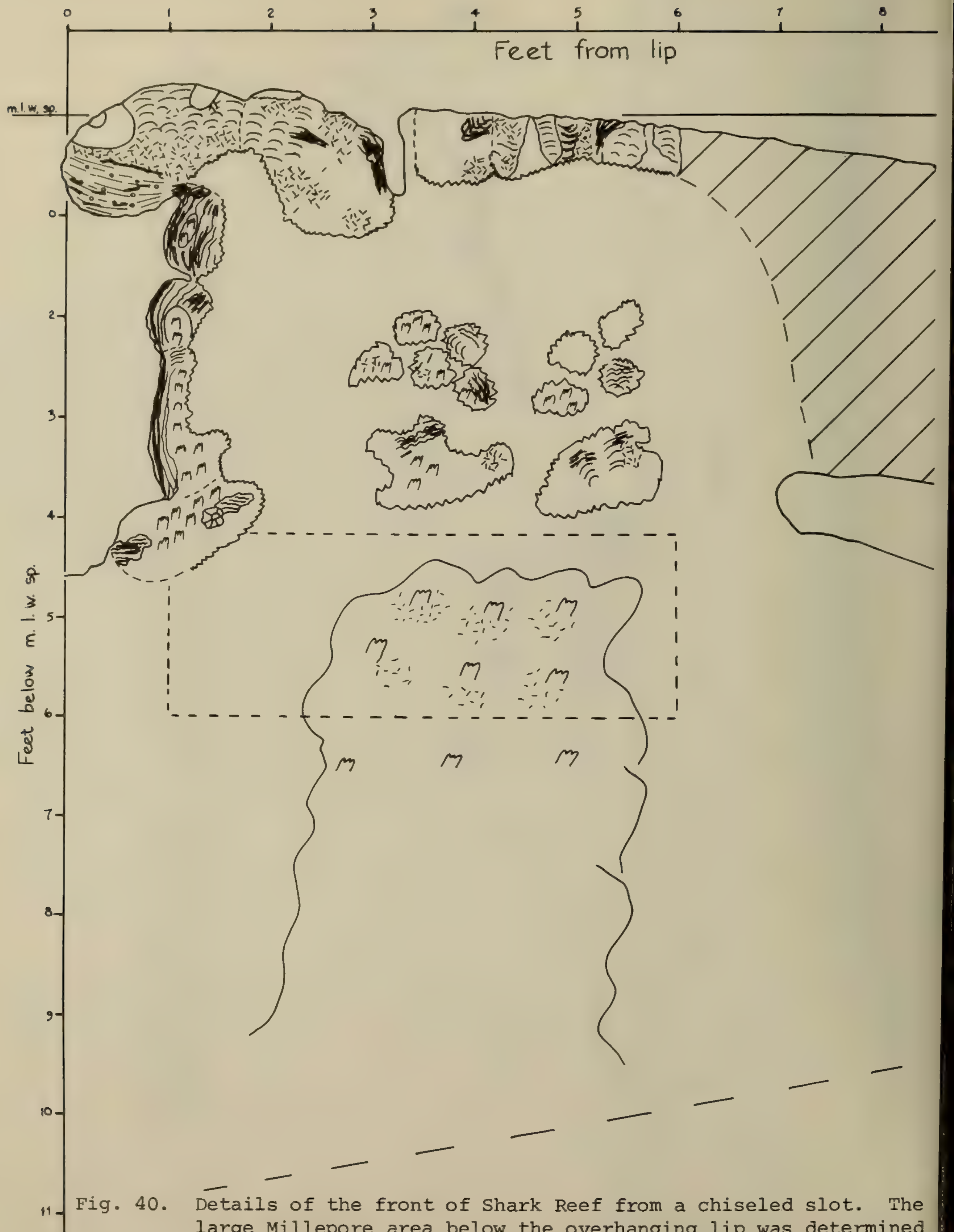


Fig. 40. Details of the front of Shark Reef from a chiseled slot. The large Millepore area below the overhanging lip was determined by repeated core-drilling. Lpm. congestum, crustose species, mostly Neogoniolithon and Porolithon above, Tenarea bermudense below lips, Homotrema, Millepore.

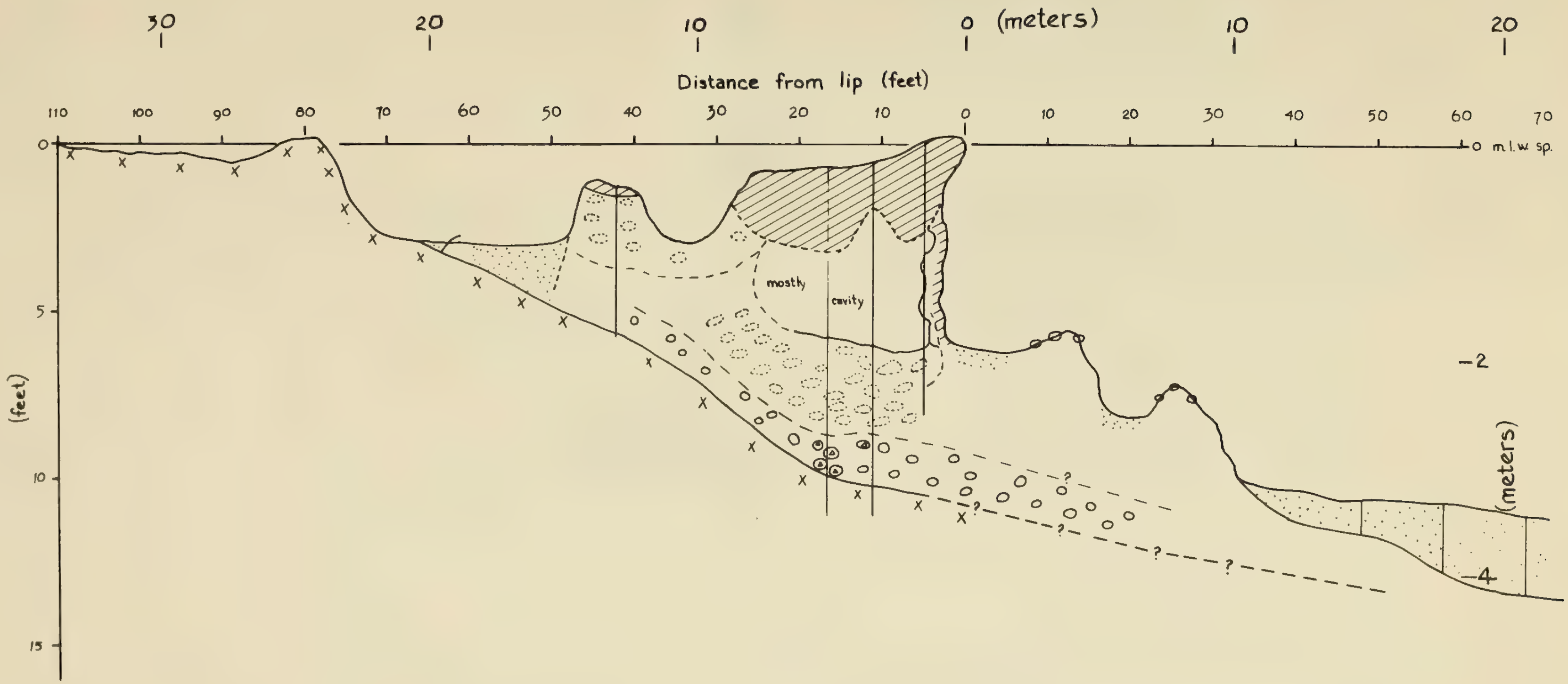


Fig. 41. Section through Stick Reef. This ridge has an obvious lobate character and our cores have apparently penetrated the cavernous junction of several boilers. No standing large coral species were found beneath the coralline cap in these cores. Caledonia pebbles and cobbles, perhaps primarily derived from colluvium, overlie the Caledonia basement under this ridge.

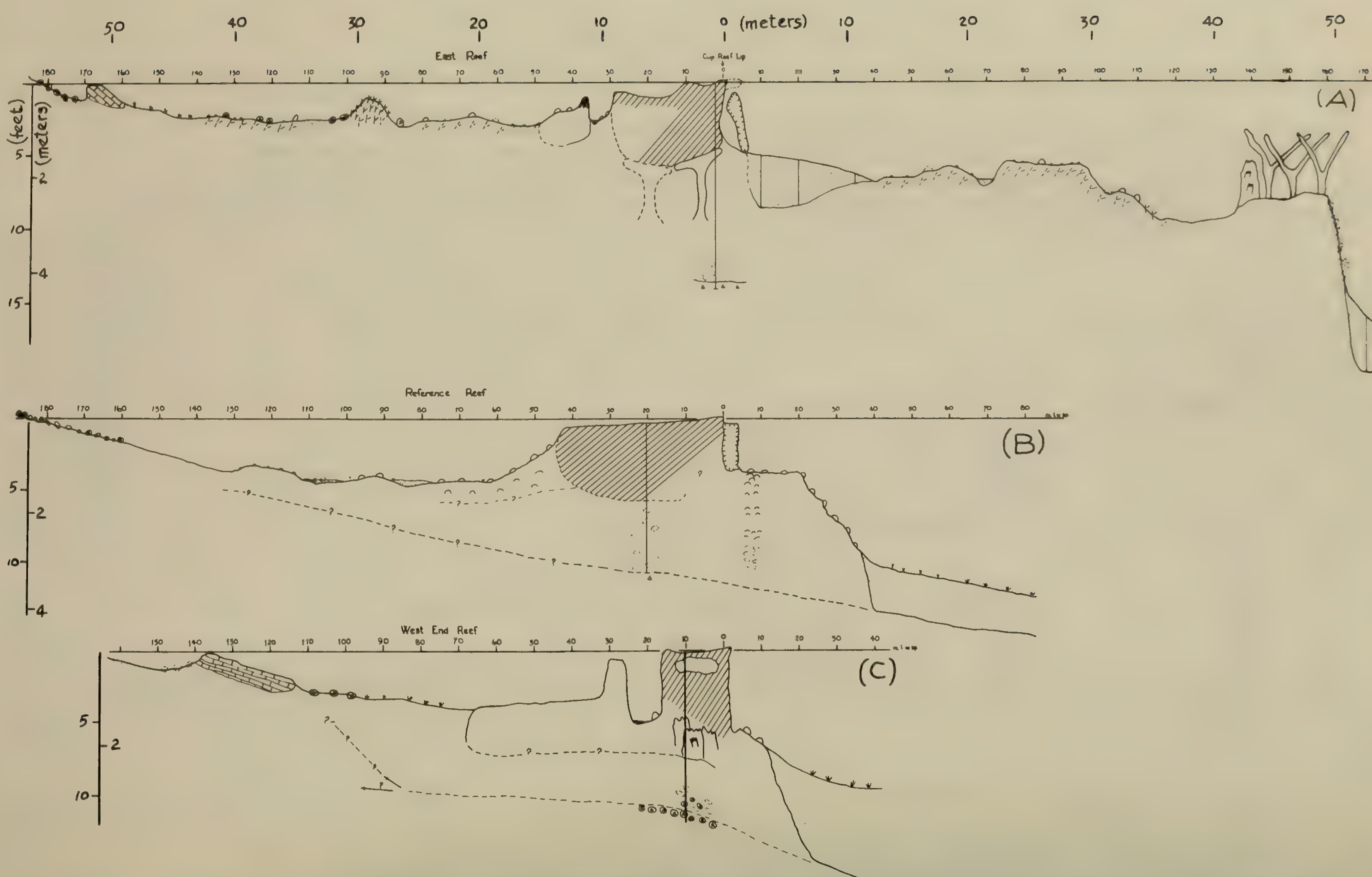


Fig. 42. Sections through East, Reference and West End Reefs. The small westernmost boilers appear to be <u>Millepore</u>-based, the <u>Millepore</u> having developed on a spit of pebbles extending down-current from the colluvial lobe.

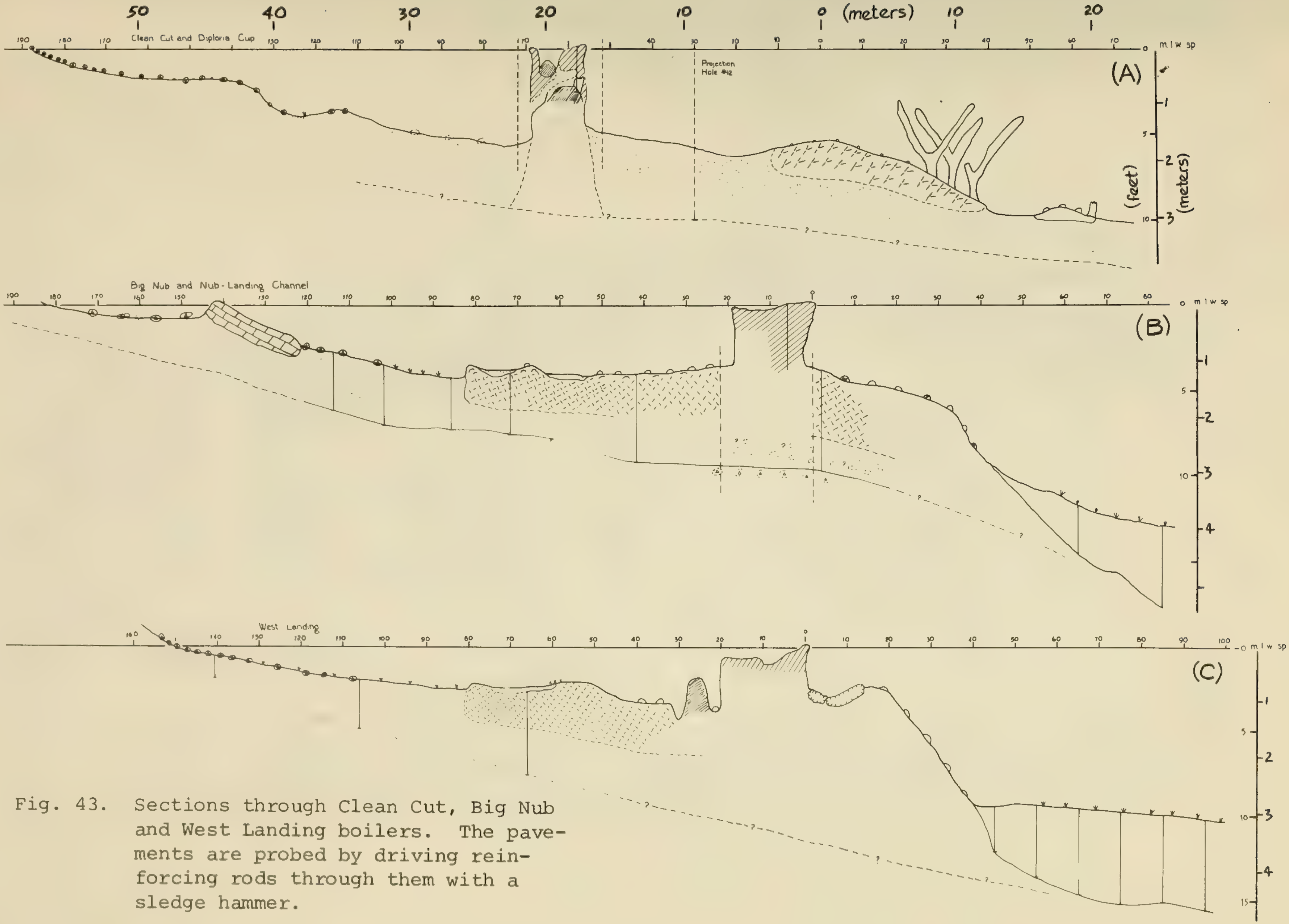


Fig. 43. Sections through Clean Cut, Big Nub and West Landing boilers. The pavements are probed by driving reinforcing rods through them with a sledge hammer.

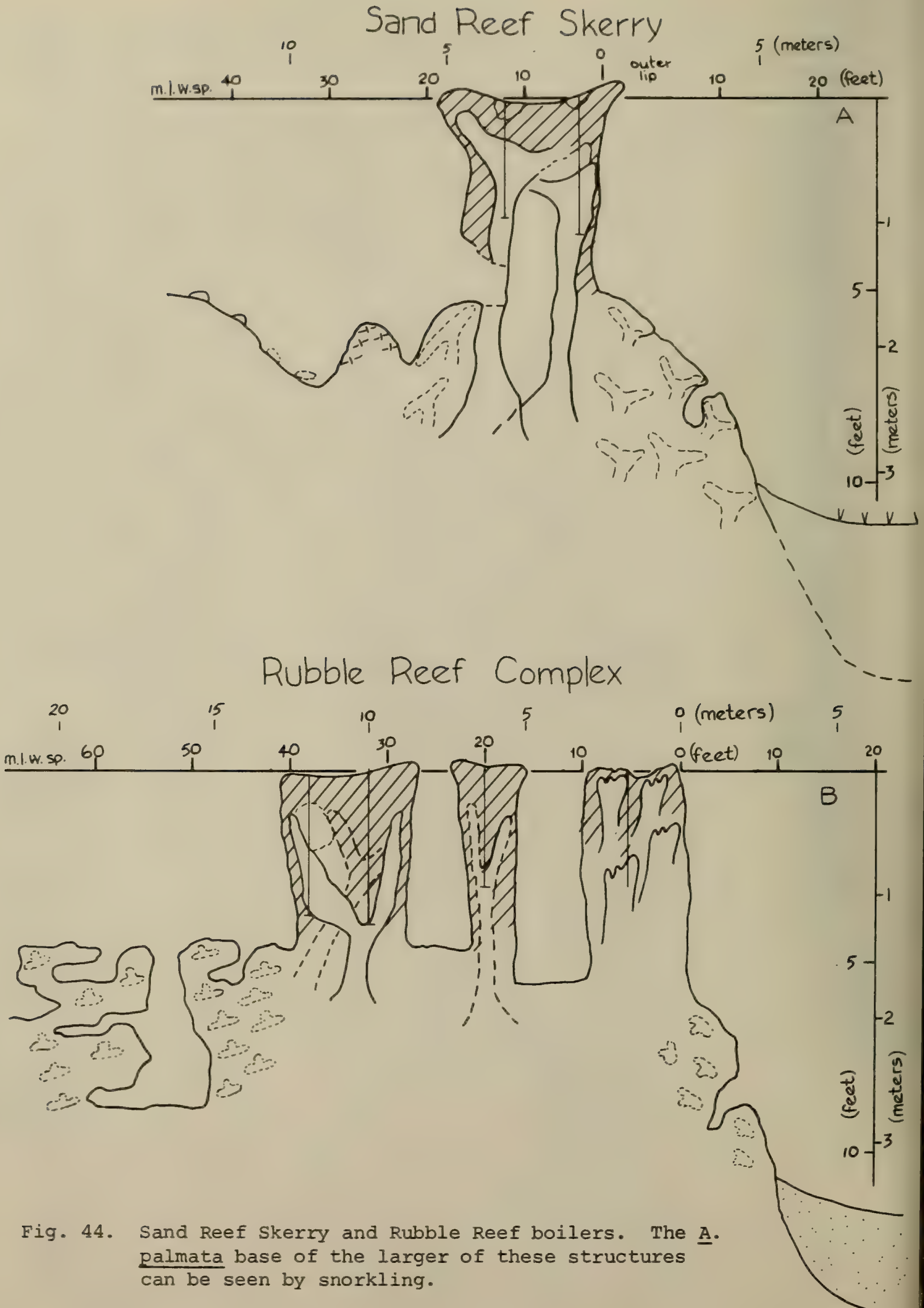


Fig. 44. Sand Reef Skerry and Rubble Reef boilers. The *A. palmata* base of the larger of these structures can be seen by snorkling.

Fig. 45. Generalized surface structure of algal ridge area in Boiler Bay. ■ coralline-constructed algal ridges; ⊞ coral pavements, mostly *Porites porites* and *Acropora cervicornis* (small variety), some *A. palmata*; ||||| living *A. palmata* colonies; ▨ dominantly live coral, mostly *P. porites* and *A. cervicornis* areas.

especially shade types, and a small brancher N. westindianum occur on the pavements, but Hydrolithon børgesenii is also often conspicuous. Much of the surface is apparently "dead" and occupied by green or red boring algae (see Adey and Boykins, 1975 - Hawaii).

We have removed several blocks from these pavements in inter and back ridge areas (Fig. 38), and in all cases, the framework was found to be either Porites porites or Acropora cervicornis with considerable Homotrema, secondary cement and perhaps 10-40% porosity. Two ages on coral were obtained on these pavements, one at 640 and the other at 940 years B.P. Apparently prior to 600-900 years B.P. most of the boiler area was densely-covered with a coral thicket much like that presently existing in far eastern areas (Fig. 37). The pavements are more or less easily probed using reinforcing rod and were cored in some cases (Figs. 39, 43B and C). Fore ridge pavements have not been cored or probed and some are A. palmata frameworks.

In some areas the back-ridge pavements support scattered rhodoliths, coralline encrusted nodules with cores of coral, terrigenous pebbles or shell. These are being studied separately.

In summary, the barrier reef in front of Boiler Bay has effectively begun to block wave action into the bay only during the past 300-500 years. Prior to that time the bay was quite open. About 4000 years B.P. rising sea level encountered the Boiler Bay colluvium. Within 1000 years, wave and current action had removed much of the weakly-consolidated colluvium leaving a lag conglômerate of Caledonia cobbles and pebbles. With the partial protection of the bay, coral colonies especially A. palmata were soon flourishing, and by 3000 years B.P. incipient algal ridges and high boilers had begun to form. This process continued up to about 500 years B.P. with numerous small boilers developing on Millepora and A. palmata colonies along with fusion of the major ridges. Apparently about 1500 to 2000 years B.P. wave action had begun to be reduced around the boilers and dense thickets of the finger corals began to develop. The richest period, in terms of coral and coralline algae development in Boiler Bay, must have been about 1000 years B.P. Since that time and especially during the past 500 years, degeneration, mostly as a result of wave blockage by the outer barrier, has become progressively more serious.

SUMMARY AND DISCUSSION

On the eastern shelf areas of St. Croix, Acropora palmata dominates shallow, turbulent water, reef communities at depths of from 1 to 6 and up to 12 meters depending probably primarily on water clarity. Once established this coral is capable of verticle reef building at rates of up to 15 mm/year, quite sufficient to match the rate of sea level rise having occurred at any time during the Holocene. However, as sea level rose over the shelf areas, A. palmata communities were not immediately established, perhaps due to wave removal of the sediments of the Pleistocene regolith. By the time coral colonies were established on the outer shelf at depths of 25-30 meters, sea levels were from 8-10 meters

above the developing reefs and the deeper and much slower-growing (1-2 mm/year) Diploria-Montastrea reefs could not keep up with sea level rise rates of from 2-5 mm/year. At shallower depths, 12-20 meters, on the inner parts of the shelves development followed the same pattern.

The siltstones and sandstones of the Cretaceous Caledonia Formation form most of the basement rock of eastern St. Croix. These weakly metamorphosed rocks of deep water volcanic origin probably underlie the carbonate shelf, and they rise rather abruptly from under the shelf near the present shoreline. Especially off modern points, narrow benches, probably of Pleistocene origin, appear to be cut in this Formation. Since the benches because of their relative elevation were probably quickly cleared of sediment as sea level rose over them 5000-3000 years B.P., coral colonies were soon established. These were early dominated by Acropora palmata and rapidly built to within 1-2 meters of the existing sea level.

Typical A. palmata colonies have a large proportion of their surface at any one time in the dead but standing condition, perhaps due to grazing or disease. This dead surface, in water less than 1-2 meters is quickly occupied by crustose coralline, and if major grazers of coralline, especially parrot fish and Diadema, cannot operate effectively due to continuous water turbulence, the crusts will accrete at rates of up to 6 mm/year. This accretion would soon develop an "A. palmata pavement", and at rates of sea level rise of the last 6000 years would build an incipient algal mound or ridge to about mean low water.

Lithophyllum congestum is a rapidly growing, branched coralline that appears to be confined, in its massively branched form, to quite turbulent areas near low water levels. A shallow subsurface algal mound colonized by L. congestum would develop quickly into the typical, intertidal, cup-shaped boiler. A group of these boilers occurring together on a bench because of their outward growing lips would tend to fuse with each other and with the surrounding coral structures. Fusion results in a reduction of wave activity on the lee side of the boilers, greater grazing in the back area and a narrowing of the fused boilers to eventually form a ridge type structure.

From about 5000 to 2000 B.P., a series of these high algal ridges developed on favorably situated benches on the eastern end of St. Croix. Massive shallow barrier type reefs were not yet developed, and the inner shelf at this time had only relatively deep coral reefs. In Boiler Bay on the northeast corner of St. Croix, a rather unusual Pleistocene colluvium, or rapid flow, of poorly consolodated boulders to pebbles in a silty matrix became exposed to wave action about 3500 years B.P. Within 500-600 years, an A. palmata community, followed by algal boilers and ridges developed on the lag cobbles from this colluvium.

Beginning about 1000 years B.P. the deeper water coral reefs on the inner shelf were reaching close enough to the surface to develop A. palmata communities. These in turn have built rapidly at rates of about 15 mm/year to near present sea levels. Due to a general west to east slope of the shelf the more westerly reefs matured first and with generally less wave action have tended to form broad reef flats. In more eastern areas, the reefs have just reached levels of -1 to -3 meters,

a few small reef flats have formed, and in some places, where sufficient wave action is present, incipient and young algal ridges are forming on the barrier reef. This barrier system is blocking wave action to the older algal ridges resulting in their destruction by grazing and burrowing organisms.

If sea level remains nearly constant for another 5000 to 6000 years, the shelf edge reefs should reach the surface and develop new barrier reefs and algal ridges. The present barrier reef and its developing ridges will then also be deprived of the required wave action and face gradual destruction by boring, burrowing and grazing organisms.

Adey and Burke (1975) describe the distribution of barrier reefs and algal ridges in the eastern Caribbean. Also, they discuss in some detail the major factors that have controlled the Holocene development of these reefs and ridges and compare their development with the equivalent structures of several of the better known Pacific islands. There is perhaps no reason to repeat that discussion in detail, but I will try to cover the salient points.

Relatively flat carbonate shelves have developed during the late Tertiary and Pleistocene to the north, east and south of most eastern Caribbean islands. While the depth of the surface of these shelves relative to present sea level is quite variable, the average depth, inshore and near the islands, is 12-20 meters. Within this range, as discussed above for St. Croix, many extensive barrier reefs have developed. These are presently reaching sea level and to various degrees are forming reef flats. Areas with a generally shallower shelf (e.g., the Grenadines) have an extensive mature reef development. Other areas (such as the southeastern part of the northern group of the Virgin Islands) have deeper shelves and have very few mature reefs. In areas of considerable turbulence, algal ridges, the equivalent of the incipient ridges on St. Croix, are forming on these barriers.

However, at depths shallower than 15 meters, relatively small benches are also locally cut into the island bedrock. These are especially strongly developed on limestone capped islands, but occur on late Tertiary volcanics as well as Cretaceous metamorphics. These benches, probably developed at high sea level stands during the late Pleistocene, are effectively local, shallow shelves and have a more mature reef system. Especially in the high wave energy St. Eustatius to Barbuda to Martinique area of the lesser Antilles, large algal ridges, to greater than 1 meter in height are developed on these shallow benches. These ridges, although limited in length, are quite analogous to the extensive algal ridge systems developed on the margins of Pacific atolls where in the cored and better known cases the pre-Holocene topography also occurs at depths of 6-10 meters.

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ANEGADA ISLAND: VEGETATION AND FLORA

by W. G. D'Arcy

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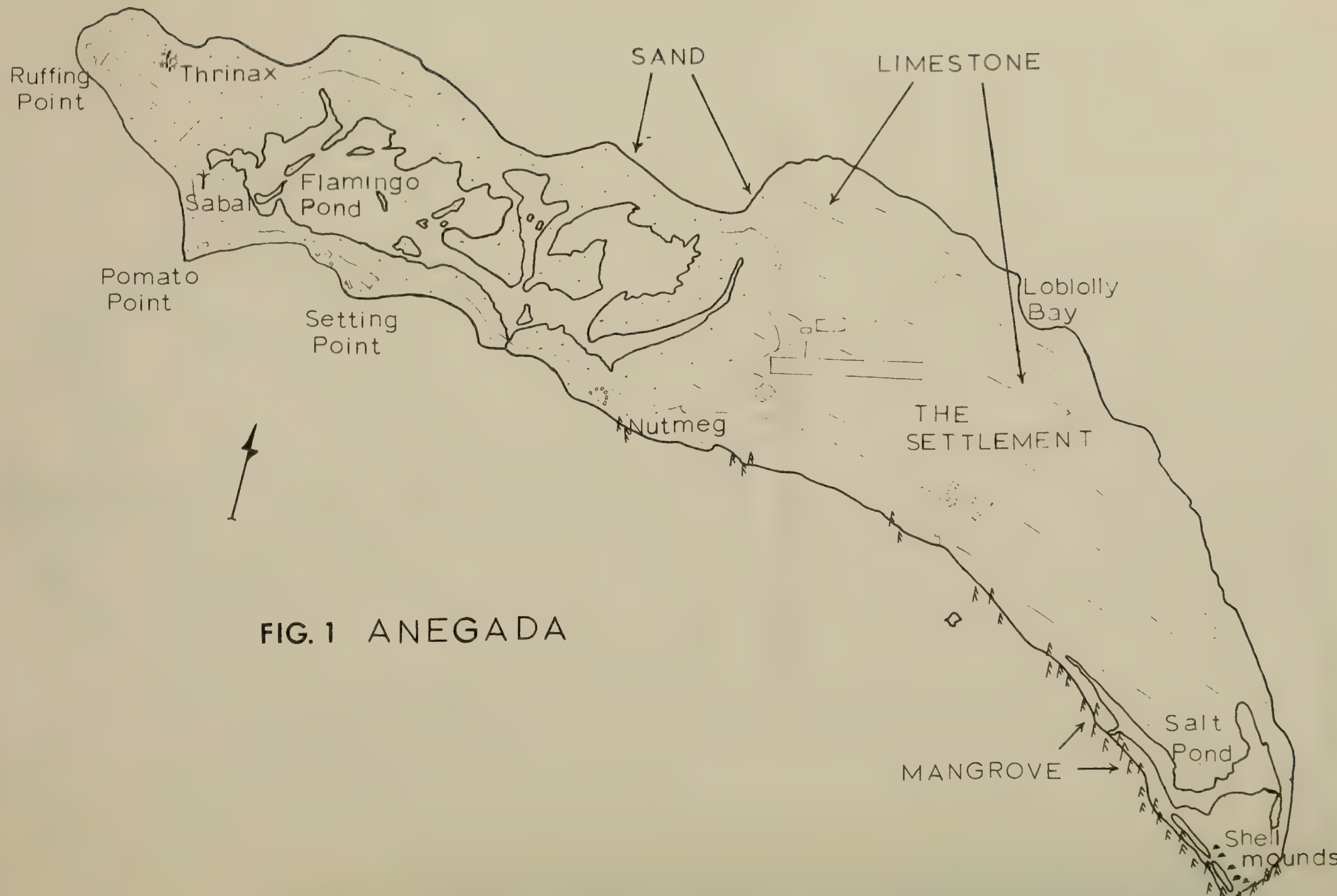

FIG. 1 ANEGADA

ANEGADA ISLAND: VEGETATION AND FLORA[1]

by W. G. D'Arcy[2]

Anegada is a low, flat limestone island isolated from other land masses by prevailing wind direction and ocean currents, and although several nearby mountainous Virgin Islands are in view on the horizon, the 13 mile nearest distance is magnified insofar as possibilities for interchange of biota is concerned. The island is situated at the northeast tangent of the Antillean arc. It is about ten miles long and two miles wide with some large salt ponds, and it is populated by a cluster of West Indian families at The Settlement and, scattered around the island, a few recently arrived families from abroad (see map, Fig. 1.). In spite of the present small population, disturbance of the vegetation is of long standing and for much of the island, of a high order. The introduction of modern construction equipment in the past three years is already having an effect on the landscape. While the flora is mainly derived from that of dry sections of Puerto Rico and the vegetation structure is much like that of Barbuda and Anguilla, there are interesting differences.

The island has drawn the attention of several workers in the past, and recently I published an account with a brief checklist of the flora and summary of previous work (D'Arcy 1971). New field work has increased knowledge about the island and this is presented here: an annotated checklist of the flora and a description of the vegetation. An assessment is made of the effects of man on the flora and landscape. General information on the island is to be found in papers by Schomburgk (1832), Britton (1916) and Beard (1942). Britton & Wilson (1923, 1925) gave a floristic account based on the collections of N. L. Britton and W. C. Fishlock, then Curator of the Botanical Station, Road Town, and Beard in his account listed important plants and discussed the vegetation. A recent study of the birds was published by LaBastille and Richmond (1973).

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1 Contribution Number 5 from Fairleigh Dickinson University West Indies Laboratory, St. Croix, U.S.V.I.

2 Present address: Missouri Botanical Garden, 2315 Tower Grove Avenue, St. Louis, Missouri 63110.

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GEOGRAPHY

Physical Features

Anegada is situated at 18°43'N and 64°19'W (The Settlement). It is ten miles long and 2-1/4 miles wide at its widest point with a surface area of 14.987 square miles (Klumb & Robbins 1960) or about 33 square km. The axis runs west by north and east by south and the overall shape is that of a crescent--concave to the Antillean arc. The greatest elevation is about 15 feet (ca 4.5 m).

Reliable rainfall data are wanting, but the amount is probably similar to that of Anguilla or Barbuda, similar flat islands at the east of the Caribbean Sea. Harris (1965) gives a mean of 39 inches for Barbuda and 45 inches for Anguilla. In this region, the months from January to April are usually dry and August to November are wet but there is great irregularity in the seasonal pattern. Even at points with comparatively high rainfall there may be periods of several months without significant rainfall (see D'Arcy 1967). Although Anegada is quite small and flat, Francis (1953) reported that "the island cumulous cloud that appeared each day reproduced remarkably the somewhat banana-shaped outline of the island." Because of the nearly continuous trade winds, this cloud probably drops little water on the island itself but may lead to precipitation in the sea to the west. Although the north coast enjoys a vigourous fanning from the trade winds, wind action inland is variable at ground level, some days being calm over much of the island and other days breezy. The breeze may be salt-laden at any point on the island.

Hurricanes strike the island infrequently but with considerable violence. Hurricane Donna of 1960 removed many of the houses in The Settlement from their foundations, and there was heavy rainfall. Schomburgk reported that a hurricane had occurred in 1819 which closed waterways and apparently reduced the mosquito population to an insignificant level.

During the winter months, a 'ground sea' coming from the north makes sailing rough and increases wave action on exposed north shores throughout the Virgin Islands. The difference in day length is about two hours between the winter and summer solstices. Temperature data are not available for the island but at Cruz Bay, St. John, some 25 miles to the southwest, the summer and winter maxima are 95 and 88° F respectively and the summer and winter minima 67 and 59° F respectively. The monthly mean temperatures range from 76.7 to 82.3° F. Both Beard and Francis reported that the daytime heat on the limestone plain was intolerable and I sometimes found the limestone pavement unpleasantly hot to touch. Temperature must impose a rigourous selection on the flora that can colonise the rock pavement and is a factor in maintaining generally xeric conditions on the island, even in times of good rainfall.

Extending out to sea along the south coast and southeast into the Anegada Passage is the Horseshoe Reef, one of the world's most

fearsome sailing hazards, vying with the reef off Anguilla and the shoals off Cape Sable in the North Atlantic in numbers of ships and lives lost. In the days of sailing transport when the Anegada Passage was a main route from Europe to the New World, this reef took a heavy toll and wrecking or spoiling was an important employment for residents of Anegada. The reef extends eight miles from East End and is five miles wide with scattered coral heads over most of its surface. Calcareous reef debris moves westward with the Antillean Stream which passes along the north coast and its narrow fringing reef. Sand is washed up on Anegada's north shore where it builds a dune of about 15 feet. The western third of the island consists of a sandy plain built up of sand blown from the north coast dunes, probably much of it across the limestone pavement which forms the eastern portion of the island. Some of this sand reenters the sea along the south coast where the dune is low or absent, and a counter-current returns some of it eastward again toward the main reef. To the west of the island's northernmost point is a ridge of sand on the sea floor extending to Jost Van Dykes some 25 miles further west.

Salt ponds cover a substantial portion of the Anegada land area. In the west, Flamingo Pond is the largest stretch of water. Surrounded on all sides by portions of the sandy plain, the western ponds have a narrow connection with the sea along the south coast, and Schomburgk mentioned a connection along the north coast which was blocked by the hurricane of 1819. There is probably considerable variation in the size of this pond depending on rain and wind conditions, but it is not apparent why drifting sand has not filled most or all of it in the century and a half since Schomburgk's visit. On Schomburgk's map the pond does not extend as far west as Pomato Point but now it extends well beyond this point. To the east, the large pond known as Salt Pond rests in a limestone saucer with exposed pavement sloping gently at the sides. Salt Pond has a narrow connection with the sea at the south side, and a fish weir in the Channel suggests some engineering by man. This pond now extends almost a mile further east on its southern arm as compared with Schomburgk's map, but the northern arm is somewhat contracted.

The eastern two thirds of the island consists of a limestone plain with here and there a shallow cover of sand, but much of the area is a naked limestone pavement. At the western end of this plain there is some exfoliating of the limestone in tiles. Puddles an inch or two deep lie in solution recesses of the pavement after a rain, and along the northern edge of the limestone plain are a few solution sink-holes or slobs 8-10 feet deep which usually contain fresh water. Recent quarrying to a depth of 20-30 feet at the western end of the plain uncovered only a homogeneous appearing unbroken mass of creamy white limestone. Dr. Harold L. Levin examined hand samples from the quarry and found the material too compacted and degraded to yield much information, but he was able to state: "The rock is a bioclastic partially recrystallized limestone containing the foraminifer _Archaias_ which ranges in age from Eocene to the Recent and has been recorded from Bermuda and Barbados."

Man Made Features

The shell mounds at East End are good evidence of the presence of pre-European man. Covering half an acre and rising about 15 feet, the older mounds are now covered with a woodland of lignum vitae (Guaiacum), satinwood (Zanthoxylum) and other species, and one must scratch the surface to see that the mounds are, in fact, made of conch. A few yards further inland (to the west) are several slate-blue mounds of more recent date lacking vegetation altogether. These rise about eight feet above the limestone pavement. The mounds have been built up parallel to the south shore facing red mangroves across a channel just wide and deep enough to accept one or two canoes. The Indians evidently took their conch in the nearby reef and came to this point, the closest landfall, to clean the catch and perhaps dry it on the nearby stone pavement. The point is well sheltered from the sea and wood was available for fires or other domestic purposes. Schomburgk mentioned some of the mounds being pulled down for making building lime and the recent mounds were probably made by European or African settlers, but a good indication of pre-European conch harvesting is still intact.

In the years between the first European settlement and the past decade, man has affected the landscape mainly through burning and cutting the woods and through the introduction of his grazing animals. The main site of habitation was probably always The Settlement and this area has had the greatest disturbance. At other points there are some signs of former presence of man, e.g., a straight row of tall coconut trees on the sandy plain northwest of Flamingo Pond well away from the sea, but such indications are few. Until recently there were neither draught animals nor vehicles and hence no roads, and there were no paved walks. Well worn paths extended to various parts of the island and the Salt Pond is bridged in various places by stepping stones. One interesting feature which, if not man made, is at least man used, is "The Creek," a muddy pond of almost perfect rectangular shape about 20 feet on a side which harbors repugnant clouds of greenish scum and two species of Eleocharis not found elsewhere on the island. This pond, much used to water cattle, is about a mile east of The Settlement. It may be the same pond where Fishlock found Panicum geminatum in October, 1918. An important feature of the Anegada landscape is the stone fencing which divides the limestone plain into a reticulum of fields of one to many acres in size. The fences are of limestone tiles or small blocks and are mostly about three feet high. Until recently all land on Anegada was owned in common and it was important for the farmer to keep up his fences in order to maintain his claim to the plots he used. With economic changes of the past few years, fences are no longer maintained and animals roam the island at large.

In the 1950's a missile tracking station was established at the extreme west end of the island and an airstrip was prepared nearby. Both facilities are now abandoned; the airstrip is partly erased and the temporary buildings of the station are in decay. A recent purchaser may put this material and the nearby land back into use.

Late in the 1960's an enterprise from London, England, contracted with the local government for a large portion of Anegada to construct a

system of hotels and a retirement colony. Early in 1971, this enterprise ran into political and apparently also financial difficulties and withdrew from the colony. During the course of the project, several physical items of the scheme were initiated or completed and these are significant for the study of the island. The map (Fig. 1) indicates their approximate positions.

--A house site (actually a house trailer) was situated at Pomato Point.
--Former occupants of Setting Point were evicted and a small beach-side hotel was built. Adjacent to this a jetty was built and several large metal buildings were erected to house equipment and a shopping facility. The Setting Point clearing involved several acres.
--Inland from Windlas Bight on the north side of the island a large electric power plant was completed but never put into operation.
--At the western end of the limestone plain a new airstrip was prepared and this is in current use.
--Near Nutmeg Point a staff housing project of about a dozen houses of greenhart wood from Guyana was erected and several houses were occupied by staff.
--Roads were cut and graded between The Settlement and Pomato Point and to the power plant on the north. In addition, motorable tracks were extended to west end, to Loblolly Point and around Flamingo Pond on the north.
--A quarry some 50 feet on a side and 25 feet deep was dug near the airport.
--For work on the projects, a number of workmen were imported from the United Kingdom and these people, some with families, camped in tents or shacks in the western part of the island. By mid 1971, all had departed.

The projects built at this time opened new areas for plants associated with disturbance, while the habitats of several farms were eliminated or drastically altered. Weeds seen on the Soares farm at Setting Point in 1970 had moved with the family to the new farm site west along the south coast when the Setting Point farm was abandoned in 1971. The airport site took over farms which residents say had been active at that time, and it is difficult to say whether the weeds now associated with the airport were newly introduced or are holdovers from the former farming activity.

The activities in the western part of the island meant new economic pursuits for the residents of The Settlement. Fences for cattle holding and boats for fishing were let decay and many new concrete block houses arose in The Settlement. The main street was paved for most of its distance and a new water catchment was built near the school. Several residents acquired motor vehicles. There are now three or four small shops instead of one.

At the close of the hotel and residential colony scheme, the government took over the physical resources of the London developers and has not yet found a firm basis for continuing the scheme. By midyear 1971 the only people living outside The Settlement were those at the Soares homestead between Setting Point and Pomato Point and one or two

caretakers for the Setting Point hotel complex. However, the present is only a lull in the inevitable march towards modern development of the island. Whether the development means tourists, residents, or industry, it is certain that the recent construction is but a token of what is to come. The surface of the island will be substantially modified in the not too distant future. One drastic proposal is for the United States Navy to use the island as a naval gunnery target in replacement for the Culebra Range (Puerto Rico) where inhabitants have objected to the proximity of the present naval range (San Juan Star, 23 February, 1972). Perhaps the Government of the Virgin Islands will be able to set aside some of the island's most interesting localities for preservation. The shell mounds at East End and the palm communities in the west (D'Arcy 1971b) would be well worth saving.

VEGETATION

The vegetation of Anegada accords well with what Beard (1944) referred to as "Evergreen Bushland" and it corresponds closely with that vegetation type as it occurs on Barbuda. The substrata and other conditions are similar and have led to accumulation of a similar flora with a like physiognomy. Photos shown by Beard, Stoffers (1957) and Harris (1965) bear this out. An important difference is in the degree to which introduced species have modified the original vegetation. Arborescent species introduced into the Leeward Islands which have become important in the vegetation such as logwood (Haematoxylon campechianum), acacia (Acacia farnesiana, A. macrantha, etc.), mesquite (Prosopis juliflora), and species of Citrus, Eucalyptus or Ananas do not occur in the wild if at all on Anegada. Tamarindus indica is the sole alien tree seen and this occurs only in limited numbers at the western side of the airport. Beard specifically mentioned the Anegada situation as a "degraded bushland," and it certainly is that, both in terms of total floristic composition and in structure. Both Beard and Harris assumed that man and his animals are almost entirely responsible for this sort of situation, but this is less so on parts of Anegada than in the areas these workers described. Anegada's vegetation may be considered under four heads: the shorelines, the sandy plain, the limestone plain, and the vegetation near man. Other writers have not distinguished between the first two of these vegetation units but on Anegada there are ample differences. The vegetation under human influence is considered below under the edaphic categories.

The Shorelines

The entire north seacoast is a high dune mostly surmounted by a littoral hedge of Suriana maritima, Tournefortia gnaphalodes and Coccoloba uvifera. This association also occurs on the south coast west of Saltheap Point, although there is almost no dune and the shrubs are seldom dense enough to be considered a hedge. Occasional plants of Cenchrus echinatus, Leptochloöpsis virgata, Sporobolus virginicus, Cyperus elegans, Sesuvium portulacastrum and Scaevola plumieri also form part of this seacoast group. Cakile lanceolata, Canavalia maritima and Ipomoea pes-caprae are quite uncommon and may, in fact, occur as frequent adventives rather than as natural components of the flora. The shores of Flamingo Pond and the other salt ponds in the west are lined

with thickets or solitary plants of Conocarpus erecta, Coccoloba uvifera, Laguncularia racemosa and Borrichia arborescens, mostly not more than 3 m tall and in the west only 1 m tall. In patches starting near Nutmeg Point and becoming a solid mass east of The Settlement, red mangroves (Rhizophora mangle) border the south coast, apparently without epiphytes or associates. Salt Pond in the east is surrounded by large areas of Batis maritima, Sueda linearis, Philoxerus vermicularis and Salicornia perennis. Along the south shore of the pond are abundant clumps of Salicornia bigelovii. Above the level of these diminutive succulents, the flora of the limestone plain begins. Behind the north coast dunes there is often a transition area where the flat limestone is covered here and there with sand from the dune. In this strip occur Tragus berteronianus, Cyperus cuspidatus, Ximenia americana, Stylosanthes hamata, Turnera diffusa, Evolvulus bracei, Borreria verticellata and Heliotropium microphyllum. These are all species of xeromorphic appearance and all except the Ximenia are diminutive. Not really forming a vegetation unit, these plants may represent an interdune flora between the littoral hedge and the interior woodland.

The Sandy Plain

The plant community on the sandy plain comprises almost a dozen frequently found species of shrubs, half a dozen species of forbs, epiphytes or lianas and a dozen or so other species occurring in small numbers or only locally. The dominants are plentiful throughout the plain and range from 2 to 3 m in height, sometimes dense, but often with spaces wide enough for a man to walk through. The growth is mostly erect and flowering is in the "canopy" or near it. Spines are absent except for the sharp leaf tips of Ernodia littoralis. The dominant shrubs are:

Byrsonima lucida
Chamaesyce articulata
Croton discolor
Cassine xylocarpa
Crossopetalum rhacoma
Dodonaea viscosa
Jacquinia arborea
Lantana involucrata
Erithalis fruticosa
Gundlachia corymbosa

Growing on these shrubs as lianas or epiphytes are:

Encyclia bifida
Tetramicra elegans
Cassytha filiformis
Jacquemontia cayensis
Cynanchum anegadensis

Nearly at ground level, Ernodea littoralis, Polygala hetacantha, Fimbristylis spadicea and Strumpfia maritima are very frequent, the Strumpfia often attaining a meter in height and breadth. Nearly two dozen other species occur on the sandy plain, some of them such as Borrichia arborescens and Leptochloöpsis virgata wandering onto the plain from nearby shoreline habitats. Trees are rare but a few Sabal causiarum palms are conspicuous, a small, leathery leaved form of Tabebuia pallida occurs in small copses, scattered trees of Pisonia subcordata, Coccoloba krugii and Bumelia obovata are present, and occasional plants of Urechites lutea provide splashes of color. In a

swale-like depression near the northwest corner of the island is a flourishing colony of the dwarf palm, Thrinax morrisii. Beneath palms and the Pisonia trees specimens of Lasiacis divaricata, Gymnanthes lucida, Passiflora suberosa and Canella winteriana hover tenaciously at the threshhold of survival.

Disturbed areas on the sandy plain have a special flora not found elsewhere on the island, all small, weedy species. The following occur on the airstrip, the house sites, or farm areas of the sandy plain:

Chloris petraea	Phyllanthus amarus
Chamaesyce blodgettii	P. caribaeus
C. prostrata	Heliotropium angiospermum
C. serpens	Physalis angulata
C. torralbasii	Portulaca oleracea

Only Portulaca oleracea of this list has been found elsewhere on Anegada.

Most of the plants composing the natural vegetation of the sandy plain occur also on the limestone to the east, some of them plentifully. Except for the endemic Cyanchum, the species are mostly widespread in the Caribbean area, although the Chamaesyce, Tetramicra, Jacquemontia and Polygala are restricted to the northeastern portion of the Caribbean. The floristic composition is clearly under edaphic control as not many of the evergreen bushland species which occur on the limestone plain manage to inhabit the sandy plain. A limited range of pollinators may add to the difficulty many species must have in establishing in this overdrained, overalkaline, undernourished substrate. It is not surprising that this vegetation includes as dominants members of such calciphilic families as the Euphorbiaceae, Celastraceae and Malpighiaceae.

Except for the obviously disturbed areas there is little in the flora or the physiognomy of the plants suggesting the influence of man or his animals. The resistance of some similar communities to floristic adulteration by species transported by man has been commented on by Sauer (1967). However, the possibility of long past use of fire or cutting out of the larger trees cannot be dismissed as reasons for the limited height of the scrub rather than the obvious wind and edaphic inhibitants to growth. On other islands, vegetation like that of Anegada's sandy plain is considered a part of the coastal dune vegetation. Palmetto Point, Barbuda, to judge from the literature and photographs may also have a sufficient area of sandy plain for it to be considered distinctive.

No observations were made of possible pollinators on the plain but the visitor is struck with the sameness of flowers of several different species. The Jacquinia, Jacquemontia, Cynanchum, Erithalis, Ernodia and Bumelia all have small, tube-like flowers, and the Croton, Chamaesyce and Polygala have differently shaped flowers of the same order of size. All of these flowers are brilliant white in the sunshine but become less conspicuous late in the day or at dusk. The Lantana involucrata has a small white flower too, but it becomes conspicuous late in the day or at dust when it takes on a purplish hue and appears almost irridescent

against the foliage. Yet another flower-form syndrome is suggested by the two orchids and the Byrsonima which have creamy flowers with a good admixture of purple from throat lines and sometimes yellowish or orange in the throat. The flower of the Strumpfia is not unlike this in color pattern.

LaBastille and Richmond (1973) reported two species of hummingbird from Anegada, both seen in numbers on beaches and one on the scrub of the sandy plain. The typical hummingbird flower, i.e., a red tube, no fragrance and situated above the ground, is absent from the native flora of Anegada except for Oplonia microphylla, and there are no such flowers at all in the beach areas or the sandy plain. It is well known that hummingbirds rely on insects as a source of protein, but there are probably few areas of the world where hummingbirds exist without flowers of the typical hummingbird pollination morphology.

Another non botanical feature seen on this vegetation, chiefly on shrubs of Crossopetalum rhacoma and Cassine xylocarpa are the abundant snails, Drymaeus virgulatus elongatus (Röding), as many as 50 per bush 2 m tall. These adhere so tightly to the branches that to pull one off strips the bark, yet after a night of wind storm, all had disappeared and two days later very few had reappeared. Spent shells of these snails are abundant on the sandy surface of the plain.

The Limestone Plain

The limestone plain holds the richest flora on the island, and while many plants may be found throughout, it is by no means homogeneous. Reasons for variations in flora and vegetation are not always apparent. At the extreme east end of the island on the shell mounds and nearby, there is a woodland with a closed canopy and trees 20 feet tall of Guaiacum, Zanthoxylum, Pisonia and other arborescent species. Not far to the west, this formation undergoes changes which may be attributed largely to grazing. The trees are smaller, there is open space between them, and there is little soil cover. The major wooded area of the island east of The Settlement could probably be classed as a thorn woodland, yet the mesquite, acacias, citrus and other species typical of thorn woodland on nearby islands are wanting here, and not even cacti are plentiful. There are a number of species with thorny trunks or spines on fleshy basal leaves, but more remarkable is the number of species (or percentage of the flora) with spiny, small leaves. Fishlockia, Comocladia, Pictetia, Pithecellobium, Caesalpinia, Malpighia, Jacquinia and Ernodea all have leathery, shiny leaves with sharp spines, a feature well represented in the floras of Cuba and Hispaniola but perhaps not common elsewhere.

A second feature of this vegetation is the tendency for plants to form "labyrinth shrubs." Such shrubs are an impenetrable mass of woody twigs and thorns with the tiny leaves well protected within, and may be a response to the presence of a nibbling herbivore, especially in the absence of grass. On Anegada these shrubs sometimes stand 1.5 m high and extend 1.5 m across, sometimes forming thickets over extensive areas. Forestiera eggersiana, Clerodendron, Lycium, Randia and Oplonia all take on this form here and such species as Zizyphus, Pithecellobium and

Caesalpinia are not far from it. Commicarpus and Jacquinia berteri have a similar appearance but their structure seems to provide less protection from grazing. This degraded bushland or anomalous thorn woodland extends to the western edge of the limestone plain with regional differences in height perhaps associated with variations in grazing pressure. Behind the north shore dune there is a dense thicket or krumholz formation of Cassine, Rhacoma and some other species which also occur on the sandy plain. Tournefortia and Ficus are also found here. Just west of The Settlement, the land is more open than elsewhere and there is more rock scattered on the surface. Here are the conspicuous stands of Plumeria alba, Agave missionum and Bursera simaruba and the cacti, Opuntia dillenii, Pilosocereus royenii and epiphytic Hylocereus trigonus. Whether this flora is really richer than elsewhere on the limestone plain is problematical, but a number of species are frequent which are not conspicuous elsewhere.

The Settlement is the most heavily grazed area on the island and it is bare of all but the most resistant species. Several diminutive species live beneath the grazing limits of even sheep and goats including Sida ciliaris, S. procumbens, Alysicarpus vaginalis, Stylosanthes hamata, Portulaca halimoides, P. quadrifida and the parasite Cuscuta umbellata as well as species of Chamaesyce. Also well established around The Settlement are a number of aliens such as Physalis cordata, Coleus amboinicus, Kalanchoë pinnata, Solanum elaeagnifolium and Aloe barbadensis.

Several species were observed only on the cut and grazed edges of the airport runway and several others were seen only near the airport entrance. Those particular to the runway are all wide ranging aliens while those seen only near the airport entrance include species which are probably native. Reasons for the special diversity at this western edge of the limestone were not evident, although disturbance is certainly an important factor. Plants found only on the runway are:

Dactyloctenium aegyptium
Chenopodium ambrosioides
Achyranthes aspera
Boerhavia erecta
Argemone mexicana
Centrosema virginianum
Rhynchosia minima
Kallstroemia pubescens
Abutilon umbellatum
Ipomoea triloba
Pectis linifolia

Plants found only near the airport entrance:

Sporobolus pyramidatus
Commicarpus scandens
Tamarindus indica
Erythroxylum rotundifolium
Euphorbia petiolaris
Rauwolfia viridis
Capparis flexuosa
Heliotropium microphyllum

THE ANEGADA FLORA

Some 210 species of vascular plants are known to grow on Anegada outside of cultivation and another 31 species are cultivated, mostly as garden ornamentals. The known non-vascular flora comprises three bryophytes, one charophyte, one blue green alga and nine lichens. There are

no pteridophytes. This flora includes one endemic genus, two endemic species of flowering plant and one endemic lichen. Most of the species occurring on Anegada occur also on Puerto Rico and on others of the Virgin Islands, but there are some which bypass these closest land masses and are disjunct on Hispaniola or Cuba or are found on one or more of the flat "limestone caribees." While many species now growing on the island are pan-caribbean or pan-tropical weeds, the identifiable adulteration of the flora outside the immediate environs of man is negligible. The pasture animals which roam the island have had a significant impact on the physiognomy of the vegetation but have not led to the establishment of many obviously alien species.

The alkaline substrate, insolation, xeric moisture regime and the effects of wind and salt spray make the island unsuitable for a great proportion of the Caribbean flora. But similar habitats are the rule on the limestone caribees, the chain of small flat coraline land masses flanking the outside of the Caribbean arc from Barbados to South Florida, and many species of flowering plants are common throughout the chain, including Anegada. Similar habitats appear in limited areas of the Greater Antilles, and some of the species from Anegada and other limestone outer islands occur in these sites. Ocean currents, prevailing winds and bird routes move in directions which tend to facilitate transport of material from Anegada to the north and west and to other islands, but discourage movement in the opposite direction, thus isolating Anegada from other biota and from the gene pools of the rest of the Caribbean. The result is the small but distinctive flora and vegetation structure, selected in the presumably short life of this recently created island with its rigorous selection regime.

The bird life of Anegada was recently described by LaBastille and Richmond (1973). They recorded two doves and a grassquit as the only graniverous species, none of these migratory. Ducks and shore birds, which sometimes feed on vegetable matter, occur as winter migrants. Of the 19 species of terrestrial habitat, only two doves, a cuckoo, an ani, two hummingbirds, a mockingbird, a thrasher, and a grassquit can be suspected of including plant material in their regular diet and none of these species is migratory. Opportunities for introduction of plant species by birds is restricted to the accident of a bird far off course coincident with his carrying propagable material.

For the most part, the character of the flora suggests an immigrant pattern where a random selection of species managed to reach and colonize the island. The Rubiaceae and Compositae, often the largest families in tropical floras, are not the largest here, and they are represented on Anegada by seven and eight genera respectively, each genus with one species, and more than half the species of these two families on Anegada can be traced to sources distant and independent of the evolutionary conditions of the northern and eastern Caribbean. But in some groups, evolution seems to be taking place on Anegada or at least the Anegada plants seem to be part of groups undergoing speciation in the region, if not participating in the same gene pools. Chamaesyce is the best example with eight species occurring on Anegada, most of them ranging through the limestone caribees or Greater Antilles, but also the Urticaceae (Pilea),

Caesalpiniaceae (Caesalpinia), Mimosaceae (Fishlockia), Malpighiaceae (Malpighia), Oleaceae (Forestiera), Asclepiadaceae (Cynanchum), Convolvulaceae (Evolvulus), Boraginaceae (Cordia, Heliotropium), each has either endemic species on Anegada or very similar and closely related species within the evolutionary theatre of the Antilles. The above does not dismiss, but neither does it require, past land connection between Anegada and other islands. Whether or not Anegada was continuous with other Virgin Islands during the pleistocene glaciations, it has had effective biological isolation of a significant order since. And because of the direction of principal vectors, a new taxon evolving on Anegada might not remain endemic for long but have its range extended downstream to other islands by wind or water.

The Checklist

The checklist is based on published reports by previous workers and the writer's own collections and observations. Four visits were made to Anegada, the first in 1959 for a few hours when no collections were made and the second in 1967 for a like time when a few collections were made (D'Arcy 1971a). Then, facilitated by the West Indies Laboratory, two visits of about a week each were made in February and August 1971 for intensive collecting. Motor transport was available on both occasions. A limited range of material collected by N. L. Britton and W. C. Fishlock was borrowed from New York Botanical Garden to clarify specific points. The main set of collections is lodged with the Missouri Botanical Garden, but duplicates and even some of the unicate collections were placed with a number of other institutions. The abbreviations for herbaria which follow collectors' numbers are those listed in Index Herbariorum Part I ed. 5 (Regnum Vegetabile 31. 1964. Utrecht).

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Format

The checklist follows the order of Britton and Wilson (1923, 1925) which is essentially that of Dalla Torre and Harms. Nomenclature has been corrected, but recourse to type specimens was made in only a few cases. Citation of "B. & W." or of a Britton or a Fishlock specimen indicates that the species was reported by Britton and Wilson (l.c.). Only cultivated species are reported solely on the basis of sight records.

A. VASCULAR PLANTS

POACEAE

[*Arundo* sp.]

Reported by Schomburgk (1832) but not collected since. He may have been referring to *Lasiacis divaricata*.

Cenchrus echinatus L.

Frequent near the sea and scattered plants on the sandy plain. D'Arcy 4815 (MO).

Chloris petraea Sw.

In chickenyard, Setting Point. D'Arcy 4830 (MO).

Dactyloctenium aegyptium (L.) Willd.

Weed around the airport. D'Arcy 5117 (MO).

Echinochloa colonum (L.) Gaertn.

On limestone pavement between The Settlement and Loblolly Bay. This grass withstands high temperatures from the heated limestone. Leaves on Anegada material have prominent purple transverse lines. D'Arcy 2127 (FLAS).

Eragrostis tenella (L.) Beauv.

Scattered clumps around the island, both on the sandy plain and the limestone and in The Settlement. D'Arcy 4808 (FAU, MO, SIU, US); 4885 (MO).

Eragrostis ciliaris (L.) R. Br. [= *E. urbaniana* sensu B. & W.]

Scattered clumps around the island. Britton & Fishlock 957 (NY); D'Arcy 4823 (MO, SIU); 5064B (MO).

Lasiacis divaricata (L.) Hitchc.

Rare, growing in shade of Pisonia trees on the sandy plain. D'Arcy 4843 (MO).

Leptochloöpsis virgata (Poir.) Yates [= Uniola virgata].

Isolated clumps, mostly near the sea, various parts of the coastline. D'Arcy 4926 (C, FAU, MO, US); 4873 (MO).

Panicum geminatum Forsk.

"Water hole near settlement." Britton & Fishlock 1016 (NY).

Panicum utowanaeum Scribn.

"Thickets, junction of rocky and sandy parts." This species has prominent brown nodes. Fishlock 45 (NY).

Paspalum laxum Lam.

Frequent isolated clumps on the sandy plain. B. & W.; D'Arcy 4798 (MO); 4858 (MO).

Sporobolus pyramidatus (Lam.) Hitchc.

In scrub west of airport. D'Arcy 4891 (MO).

Sporobolus virginicus (L.) Kunth

At edge of Flamingo Pond; sandy plain near the sea. D'Arcy 4897 (MO, SIU).

Tragus berteronianus Schult.

Abundant locally in interdune area behind Loblolly Bay. D'Arcy 4955 (C, MO).

CYPERACEAE

Abildgaardia ovata (Burm. f.) Kral

B. & W. [as A. monostachya (L.) Hassk.].

Cyperus cuspidatus H.B.K.

B. & W.

Cyperus elegans L.

Scattered behind dunes of north shore, Loblolly Bay. B. & W.; D'Arcy 4922 (MO); 4923 (MO).

Cyperus humilis Kunth

Western portion of the limestone plain. D'Arcy 4906A (MO).

Cyperus planifolius Rich.

Abundant but widely scattered on the sandy plain. B. & W. [as C. brunneus Sw.]; D'Arcy 4847 (MO); 4849 (MO); 4857 (MO).

Eleocharis atropurpurea (Retz.) Kunth

Forming dense mats in and around "The Creek," a muddy pond northeast of The Settlement. D'Arcy 5144 (C, IJ, MO).

Eleocharis mutata (L.) R. & S.

A few clumps in "The Creek." D'Arcy 5067 (MO, SIU).

Fimbristylis inaguensis Britt.

"Sandy plain, West End." Britton & Fishlock 966 (NY).

Fimbristylis spadicea (L.) Vahl

Scattered clumps around the sandy plain. D'Arcy 4811 (BM, C, FAU, MO, SIU); 4836 (FAU, MO).

ARECACEAE

Cocos nucifera L.

A few trees around The Settlement and a small avenue at the west end well away from the sea. Sight record.

Sabal causiarum (Cook) Becc.

A few plants on the sandy plain (cf. D'Arcy 1971b). D'Arcy 4950 (FAU, MO, SIU).

Thrinax morrisii Wendl.

A numberous colony in a swale near West End. (cf. D'Arcy 1971b). B. & W.; D'Arcy 5096 (A, MO, SIU).

BROMELIACEAE

Bromelia pinguin L.

Sparingly cultivated as a hedge around The Settlement. Sight record.

Tillandsia utriculata L.

Occasional in *Pisonia* trees in various parts of the island. B. & W.; D'Arcy 4899 (MO).

COMMELINACEAE

Commelina elegans Kunth

B. & W.

Setcreasea purpurea Boom

Cultivated in The Settlement for ornament. Sight record.

LILIACEAE

Aloe barbadensis Mill.

Naturalized on limestone pavement in and to the immediate west of The Settlement. Sight record.

AMARYLLIDACEAE

Agave missionum Trel.

Abundant and conspicuous on the limestone plain west of The Settlement. B. & W.; D'Arcy 4910 (MO).

Furcraea tuberosa Ait. f.

A solitary plant cultivated in The Settlement. B. & W.; D'Arcy 4982 (IJ, MO).

Pancratium sp.

Cultivated for ornament in The Settlement. Sight record.

Sansevieria metallica Gérôme & Labroy

Cultivated for ornament in The Settlement. Sight record.

ORCHIDACEAE

Encyclia bifida (Aubl.) Britt. & Wils.

Abundant on the sandy plain where it grows as an epiphyte on low shrubs, the scapes waving above the scrub. Occasional plants occur on trees in eastern parts of the island. D'Arcy 4827 (C, DAO, FAU, FTG, GH, IJ, MO, NSW, NY, SIU).

Spiranthes stahlii Cogn. in Urb.

B. & W. [as _Mesadenus lucayanus_ (Britt.) Schlecht.].

Tetramicra elegans (Hamilt.) Dogn.

Abundant in localized patches on the sandy plain as an epiphyte on low shrubs. B. & W.; D'Arcy 4831 (BC, C, FAU, FTG, IJ, MO, NSW, P, PMA); 5102 (MO).

MORACEAE

Ficus citrifolia Mill. var. _citrifolia_

Abundant on the limestone plain west of The Settlement and apparently cultivated in The Settlement itself. D'Arcy 4907 (MO, SIU); 4949 (BM, C, FAU, IJ, MO, SCZ, US).

Ficus citrifolia Mill. var. _brevifolia_ (Nutt.) D'Arcy

A few trees west of The Settlement along the main road. The sterile specimen cited was identified by its red bark. D'Arcy 5075 (MO).

URTICACEAE

Pilea microphylla (L.) Liebm.

Britton & Wilson reported three species of _Pilea_ which may be interpreted as variants of _P. microphylla_. At the edges of temporary pools and under low shrubbery on the limestone plain east of The Settlement, a race of this species forms frequent mats of delicate greenery and resembles what is frequently assigned to _P. microphylla_ var. _herniaroides_ (Sw.) Griseb. The erect, succulent stemmed variant commonly called "Artillery Plant" was seen cultivated for ornament in The Settlement but was not collected. B. & W. [as _P. margarettae_ Britt., _P. microphylla_ and _P. tenerrima_ Miq.]; D'Arcy 5064 (MO).

OLACACEAE

Schoepfia obovata C. Wright

On the limestone plain west of The Settlement. D'Arcy 5978 (A, BM, C, FAU, IJ, MO).

Ximenia americana L.

Seen only in dense thickets behind Loblolly Bay. D'Arcy 4924 (MO).

LORANTHACEAE

Dendropemon caribaeum Krug & Urb.

Frequent on _Pisonia_ trees. B. & W.; D'Arcy 4961 (MO); 5097 (A, MO,SIU).

POLYGONACEAE

Coccoloba krugii Lindl.

Copses on the sandy plain and also on limestone. B. & W.; D'Arcy 2138 (FLAS); 4845 (MO, SIU, US); 5124 (A, MO).

Coccoloba uvifera (L.) Lindl.

Frequent coastal shrub and scattered clumps around the sandy plain. B. & W.; D'Arcy 4810 (MO).

CHENOPODIACEAE

Chenopodium ambrosioides L.

Weed at the airport. D'Arcy 5113 (MO, SIU).

Chenopodium murale L.

Weed in The Settlement. D'Arcy 4981 (MO).

Salicornia bigelovii Torr.

Forming large masses on the south shore of the large Salt Pond in the eastern part of the island, rooting in a layer of mud covering the limestone pavement. D'Arcy 4963 (BM, C, FAU, IJ, MO, SIU, US).

Salicornia perennis Mill.

Frequent in shallow fresh and brackish water ponds in the eastern parts of the island; also along the south shore. B. & W.; D'Arcy 2120 (FLAS); 4916 (MO, SIU).

Sueda linearis (Ell.) Moq.

Behind the dunes on the north shore and at scattered points on the limestone plain. D'Arcy 4972 (MO); 5183 (MO).

AMARANTHACEAE

Achyranthes aspera L.

Weed at the airport. D'Arcy 5119 (MO).

Achyranthes portoricensis (Ktze.) Standl.

B. & W. [a specimen to support this record was not located at NY].

Amaranthus caudatus L.

Cultivated for ornament in The Settlement. Sight record.

<u>Amaranthus crassipes</u> Schlecht.

Weed near habitation in various parts of the island. D'Arcy 4853 (MO); 4983 (MO).

<u>Lithophila muscoides</u> Sw.

Common, grazed ground of the limestone plain. B. & W.; D'Arcy 4884 (A, BM, C, FAU, IJ, MO, SIU, US).

<u>Philoxerus vermicularis</u> (L.) Beauv.

Loblolly Bay. B. & W.; D'Arcy 4945 (MO).

NYCTAGINACEAE

<u>Bougainvillia spectabilis</u> Willd.

Cultivated for ornament in The Settlement and around other houses. Sight record.

<u>Boerhavia diffusa</u> L.

Weed in The Settlement, rare. D'Arcy 4909B (MO).

<u>Boerhavia erecta</u> L.

Weed at the airport. D'Arcy 5114 (MO).

<u>Commicarpus scandens</u> (L.) Standl.

Plentiful on disturbance northwest of the airport. D'Arcy 4938 (MO, SIU).

<u>Mirabilis jalapa</u> L.

Cultivated for ornament. Sight record.

<u>Pisonia subcordata</u> Sw.

A plentiful tree except on the sandy plain where rare. B. & W.; D'Arcy 4875 (MO, SIU).

BATIDACEAE

<u>Batis maritima</u> L.

Plentiful near the seacoasts and near the ponds. D'Arcy 4803 (MO).

AIZOACEAE

Cypselea humifusa Turp.

On the sandy plain near the ponds. B. & W.; D'Arcy 5084 (MO).

Sesuvium portulacastrum (L.) L.

Disturbed areas near beaches. D'Arcy 4931 (MO).

PORTULACACEAE

Portulaca halimoides L.

Plentiful in The Settlement and other disturbed or grazed areas, also the sandy plain. Britton & Fishlock 1060 (NY); Fishlock 30 (NY); D'Arcy 4975 (MO).

Portulaca oleracea L.

Plentiful in The Settlement and other points of disturbance. B. & W.; D'Arcy 4974 (C, FAU, IJ, MO, SCZ, SIU, US).

Portulaca quadrifida L.

Plentiful on sand in and around The Settlement. D'Arcy 4902 (MO).

Talinum triangulare (Jacq.) Willd.

Cultivated in The Settlement. Sight record.

ANNONACEAE

Annona squamosa L.

A few cultivated trees in The Settlement. D'Arcy 4910 (MO).

LAURACEAE

Cassytha filiformis L.

Most plentiful on the sandy plain sometimes forming bright orange masses on herbs and shrubs; infesting *Ernodia*, *Coccoloba* and especially *Dodonaea*. D'Arcy 4817 (MO; 4837 (MO).

PAPAVERACEAE

Argemone mexicana L.

A small patch near the airport entrance. D'Arcy 4934 (MO).

CRUCIFERAE

<u>Cakile</u> <u>lanceolata</u> (Willd.) O. E. Schulz

Infrequent by the sea. D'Arcy 4816 (MO).

<u>Capparis</u> <u>cynophalophora</u> L.

Scattered trees on the limestone plain, several just west of The Settlement. D'Arcy 4898 (C, FAU, IJ, MO, SIU, US).

<u>Capparis</u> <u>flexuosa</u> (L.) L.

Scattered trees on the limestone plain. D'Arcy 4874 (MO).

MORINGACEAE

<u>Moringa</u> <u>oleifera</u> Lam.

Cultivated at The Settlement. Sight record.

CRASSULACEAE

<u>Kalanchoë</u> <u>pinnata</u> (Lam.) Pers.

Plentiful clumps in and near The Settlement. D'Arcy 4894 (MO).

<u>Kalanchoë</u> <u>somaliensis</u> Hook. f.

Cultivated for ornament in The Settlement. Sight record.

MIMOSACEAE

<u>Desmanthus</u> <u>virgatus</u> (L.) Willd.

Only a few plants seen at East End. D'Arcy 5068 (MO).

<u>Fishlockia</u> <u>anegadensis</u> (Britt.) Britt. & Rose

Most plentiful west of The Settlement, it occurs throughout wooded portions of the limestone plain. Until plants are at least several dm tall, the leaves are pinnate, several-foliolate in the fashion of many species of <u>Acacia</u>. Even the smallest juvenile seen was spiny. A second view of the plant showed that this writer's earlier report of spines 8 cm long is exaggerated: the longest are 3-4 cm, still formidable. B. & W.; D'Arcy 2124 (FLAS); 4903 (FAU, MO, SIU, US); 4909C [juvenile] (MO); 4976 [juvenile] (A, MO).

<u>Pithecellobium</u> <u>unguis-cati</u> (L.) Mart.

Plentiful west of The Settlement. B. & W.; D'Arcy 4947 (FAU, MO, SIU).

CAESALPINIACEAE

Caesalpinia ciliata Urb.

Rare, occurring on the limestone plain west of The Settlement. D'Arcy 4872 (C, FAU, IJ, MO, SIU, US).

Caesalpinia pulcherrima (L.) Sw.

Cultivated for ornament in The Settlement. Sight record.

Cassia bicapsularis L.

The Settlement. B. & W.; D'Arcy sight record.

Cassia glandulosa var. *swartzii* (Wickstr.) J. F. Macbr.

A rare plant behind the dunes. B. & W.; D'Arcy 4921 (MO).

Cassia polyphylla Jacq.

"Tree 4 m tall, rocky plain near settlement." Britton & Fishlock 1034 (NY).

Cassia sophera L.

An uncommon weed in The Settlement. Britton & Fishlock 995 (NY); D'Arcy 2123 (FLAS, MO) [reported as *C. occidentalis* L. by D'Arcy 1971b].

Delonix regia (Boj.) Raf.

One large cultivated tree in The Settlement. Sight record.

Tamarindus indica L.

Several large trees near the airport. D'Arcy 4937 (A, BM, C, FAU, IJ, MO, SIU, US).

FABACEAE

Alysicarpus vaginalis (L.) D.C.

Plentiful on limestone pavement. D'Arcy 5132 (MO).

Canavalia maritima L.

Only a single, sterile plant seen on the beach near East End. D'Arcy 4967 (MO).

Centrosema virginianum (L.) Benth.

Weed near the airport. B. & W.; D'Arcy 4936B (FAU, MO, SIU).

Crotalaria lotifolia L.

B. & W.

Galactia dubia DC.

On the limestone plain. D'Arcy 2116 (MO).

Pictetia aculeata (Vahl) Urb.

A frequent shrub on the limestone plain. B. & W.; D'Arcy 2135 (FLAS); 4865 (MO); 4896 (C, FAU, MO, SIU).

Piscidia carthaginensis Jacq.

D'Arcy 4877 (MO).

Sophora tomentosa L.

B. & W.

Stylosanthes hamata (L.) Taub.

Behind Loblolly Bay and in The Settlement. B. & W.; D'Arcy 5112L (MO).

Rhynchosia minima (L.) DC.

Weed at the airport. D'Arcy 5116 (MO).

ERYTHROXYLACEAE

Erythroxylum rotundifolium Lunan

Thickets, west side of the airport. D'Arcy 4946 (MO).

ZYGOPHYLLACEAE

Guaiacum officinale L.

Plentiful near East End where one of the dominant trees, reaching 5 m tall. D'Arcy 4969 (BM, C, FAU, IJ, MO, SCZ, SIU, US).

Kallstroemia pubescens (G. Don) Dandy

Occasional plants at and near the airport. D'Arcy 4935 (MO, SIU); 5115 (MO).

MALPIGHIACEAE

Bunchosia glandulosa . (Cav.) DC.

One of the dominants on the sandy plain and also occurring on

limestone west of The Settlement. D'Arcy 4951 (MO); 4952 (MO, SIU); 4985 (FAU, IJ, MO, SIU, SCZ).

Byrsonima lucida (Mill.) DC.

Plentiful on the sandy plain. B. & W. [as B. cuneata (Turcz.) P. Wils.]; D'Arcy 4820 (A, FAU, IJ, MO, SIU).

Malpighia infestissima (Rich. ex A. Juss.) Niedz.

Rare, seen only in immature state on limestone west and north of The Settlement and again south of the airport. B. & W.

Malpighia linearis Jacq.

A plentiful shrub near The Settlement but not seen elsewhere. B. & W.; D'Arcy 2121 (FLAS); 4936A (MO).

Stigmaphyllon periplocifolium (Desf.) A. Juss.

Scattered plants along the road west of The Settlement. D'Arcy 4863 (IJ, MO).

RUTACEAE

Amyris elemifera L.

Plentiful on the limestone plain. B. & W.; D'Arcy 2126 (FLAS); 4954 (FAU, IJ, MO, SCZ, SIU); 5081 (FAU, MO, SIU); 5110 (MO, SIU).

Zanthoxylum flavum Vahl

Occasional shrubs on the sandy plain and one of the dominant trees near East End. D'Arcy 4953 (MO); 4968A (MO).

SURIANACEAE

Suriana maritima L.

The dominant shrub on many coastal dunes. B. & W.; D'Arcy 4813 (MO); 4856 (MO); 4925 (A, FAU, MO, SIU, US).

BURSERACEAE

Bursera simaruba (L.) Sarg.

On the limestone plain west of The Settlement. D'Arcy 4890 (MO).

POLYGALACEAE

Polygala hetacantha Urb.

Frequent but scattered plants on the sandy plain; also on disturbed

soil on the sandy plain (chickenyards). B. & W.; D'Arcy 4818 (BM, C, FAU, IJ, MO, SIU, US).

EUPHORBIACEAE

Acalypha ?setosa A. Rich.

Weed in The Settlement. The specimen (staminate) is not adequate for firm identification to species. D'Arcy 4901 (MO).

Acalypha wilkesiana (L.) Poit.

Cultivated for ornament. Sight record.

Argythamnia candicans Sw.

Weed in The Settlement, also behind Loblolly Bay, on sand or rock. Britton & Fishlock 999 (NY); Fishlock 13 (NY); D'Arcy 2115 (MO).

Ateramnus lucidus (Sw.) Rothm.

Scattered plants on the sandy plain. D'Arcy 4855 (MO) [as Gymnanthes lucida Sw.].

Chamaesyce articulata (Aubl.) Britt.

Plentiful on the sandy plain, occasional on the limestone plain. B. & W.; D'Arcy 4796 (A, FAU, IJ, MO, SIU, US, USF).

Chamaesyce blodgettii (Engelm.) Small

Weed on the sandy plain, mostly on roadways and near house sites; according to Britton & Wilson also on rocks. B. & W.; D'Arcy 5100 (MO); 5103 (MO).

Chamaesyce mesembrianthemifolia (Jacq.) Dugand

B. & W. [as C. buxifolia (Lam.) Small]; D'Arcy 4697 (BM, C, FAU, IJ, MO, SCZ, SIU, US).

Chamaesyce hirta (L.) Millsp.

Weed around The Settlement. D'Arcy 4909A (MO).

Chamaesyce prostrata (Ait.) Small

Weed around houses and in farmyards, the sandy plain and The Settlement. D'Arcy 4821 (MO, SIU); 4822 (FAU, MO, SIU, USF); 5131 (MO).

Chamaesyce serpens (H.B.K.) Small

Weed around houses and in farmyards, the sandy plain. B. & W.; D'Arcy 5086A (MO); 5099 (MO, USF).

Chamaesyce _torralbasii_ (Urb.) Millsp.

Weed around building site on the sandy plain. D'Arcy 4928 (A, BM, C, IJ, MO, SIU).

Chamaesyce _turpinii_ (Boiss.) Millsp.

Plentiful on sand and rock on the limestone plain. Britton & Fishlock 998 (MO) [as _C._ _anegadensis_ Millsp.]; D'Arcy 4956 (IJ, MO, USF); 5112J (MO).

Codiaeum _variegatum_ (L.) Blume

Cultivated for ornament. Sight record.

Croton _betulinus_ Vahl

Plentiful on the limestone plain. B. & W.; D'Arcy 2113 (FLAS); 4865B (MO); 5123 (A, MO).

Croton _discolor_ Willd.

One of the dominants on the sandy plain and also occurring on limestone. The pubescence of this species exhibits exceptional variability on Anegada, ranging from yellow-green to brownish. The leaf size and shape also vary widely. B. & W.; D'Arcy 2125 (FLAS); 4920 (MO, US).

Euphorbia _milii_ Ch. des Moulins

Much cultivated for ornament. Sight record.

Euphorbia _petiolaris_ Sims

Fairly plentiful west of the airport. B. & W. [as _Aklema_ _petiolare_ (Sims) Millsp.]; D'Arcy 2137 (FLAS); 4896 (MO); 4942 (A, BM, C, FAU, IJ, MO, SIU, US); 5080 (MO, SIU).

[Hippomane mancinella L.]

Previously reported in error. Not known on the island.

Jatropha _gossypifolia_ L.

Plentiful around The Settlement. D'Arcy 4860 (MO).

Pedilanthus _tithymaloides_ (L.) Poit.

Cultivated in The Settlement. Sight record.

Phyllanthus _amarus_ Schum. & Thonn.

Weed around houses on the sandy plain. D'Arcy 4933 (MO).

Phyllanthus _caribaeus_ Urb.

Weed around houses on the sandy plain. D'Arcy 5089 (MO).

Phyllanthus _polycladus_ Urb.

On limestone pavement near The Settlement and behind Loblolly Bay. The Britton & Fishlock specimen, although sterile, is an erect, slender plant some 40 cm tall and supports Webster's (1957) concept of this taxon as a subspecies of _P._ _pentaphyllus_ Griseb. The D'Arcy collections, however, matching closely the type of _P._ _polycladus_ (Puerto Rico, Sintenis 3440 (MO)), give strong support for considering this as a distinct species. The type of _P._ _pentaphyllus_ (Cuba, Wright 1938 (MO)) is a tiny plant with erect, filiform stems while that of _P._ _polycladus_ is much sturdier. Britton & Fishlock 1000 (MO); D'Arcy 5112K (MO); 5134 (MO).

Ricinus _communis_ L.

Cultivated in The Settlement. Sight record.

ANACARDIACEAE

Comocladia _dodonaea_ (L.) Urb.

Common on the limestone plain, especially near East End. D'Arcy 4886 (C, MO).

RHAMNACEAE

Colubrina _arborescens_ (Mill.) Sarg.

Common west of The Settlement. B. & W. [as _C._ _colubrina_ (Jacq.) Millsp.]; D'Arcy 2128; 4879 (MO, SIU).

Colubrina _elliptica_ (Sw.) Brizicky & Stern

B. & W. [as _C._ _reclinata_ (L'Her.) Brongn.]

Krugiodendron _ferreum_ (Vahl) Urb.

B. & W.

Reynosia _uncinata_ Urb.

Plentiful west of The Settlement. B. & W.; D'Arcy 4870 (MO); 4888 (MO).

Zizyphus _rignonii_ Delp.

Plentiful shrub on the limestone plain. B. & W. [as _Sarcomphalus_ _domingensis_ (Spreng.) Krug & Urb.]; D'Arcy 2140 (MO); 2180 (FLAS); 4906 (FAU, MO, SIU); 5082 (MO, SIU).

CELASTRACEAE

Cassine xylocarpa Vent.

One of the dominant shrubs on the sandy plain. B. & W. [as *Elaeodendrum xylocarpum* (Vent.) DC.]; D'Arcy 4800 (A, FAU, IJ, MO, SIU, US); 4833 (FAU, MO, SCZ, SIU, US); 4835 (MO, SIU); 4846 (MO); 4919 (MO).

Crossopetalum rhacoma Cranz

One of the dominant shrubs on the sandy plain. B. & W. [as *Rhacoma crossopetalum* L.]; D'Arcy 2139 (A); 4932 (BM, C, FAU, IJ, MO, SIU, US).

Gyminda latifolia (Sw.) Urb.

On the limestone plain. B. & W.; D'Arcy 2130 (MO); 4812 (FAU, MO, SIU).

Schaefferia frutescens Jacq.

Scattered plants west of The Settlement. D'Arcy 4940 (MO); 4986 (MO, SIU).

SAPINDACEAE

Dodonaea viscosa Jacq. var. *spatulata* (J. E. Sm.) Benth.

By far the most plentiful of the dominant shrubs on parts of the sandy plain. B. & W. [as *D. ehrenbergii* Schl.]; D'Arcy 4828 (C, FAU, IJ, MO, SCZ, SIU, US, USF); 4842 (MO, SIU).

Serjania polyphylla (L.) Radlk.

Near East End. B. & W.; D'Arcy 4968B (MO).

VITACEAE

Cissus trifoliata (L.) L.

Frequent west of The Settlement. B. & W.; D'Arcy 4866 (MO).

TILIACEAE

Corchorus hirsutus L.

Infrequent plants throughout the island. B. & W.; D'Arcy 4839 (MO); 4959 (MO).

MALVACEAE

Abutilon umbellatum (L.) Sweet

Weed at the airport. D'Arcy 5121 (MO).

Hibiscus sp.

Cultivated for ornament. Sight record.

Sida ciliaris L.

Plentiful on heavily grazed limestone at The Settlement. B. & W.; D'Arcy 4979B (MO); 5112H (MO).

Sida procumbens Sw.

Plentiful on heavily grazed limestone at The Settlement. B. & W.; D'Arcy 4979A (MO).

STERCULIACEAE

Melochia tomentosa L.

Infrequent on the limestone plain. D'Arcy 4867 (FAU, IJ, MO, SCZ, SIU, US).

Waltheria indica L.

"Edge of cultivation." Fishlock 39 [as *W. americana* L.].

CANELLACEAE

Canella winteriana (L.) Gaertn.

Infrequent, in shade of *Pisonia* trees on the sandy plain. B. & W.; D'Arcy 4840 (MO).

TURNERACEAE

Turnera diffusa Willd.

Seen only behind dunes at Loblolly Bay where plentiful. D'Arcy 2112 (FLAS, MO); 5111 (A, FAU, MO, SIU).

PASSIFLORACEAE

Passiflora suberosa L.

Occasional in trees on both sandy plain and limestone plain. B. & W. [as *P. pallida* L.]; D'Arcy 4834 (MO); 4941 (MO).

CACTACEAE

Hylocereus trigonus Safford

Locally conspicuous on trees on the limestone plain west of The Settlement but not seen elsewhere. D'Arcy 4930 (MO).

Melocactus intortus (Mill.) Urb.

Plentiful around The Settlement. B. & W. [as *Cactus intortus* Mill.]; D'Arcy sight record.

Opuntia dillenii (Ker.-Gawl.) Haw.

Plentiful in heavily grazed areas near The Settlement. D'Arcy 4929 (MO).

Pilosocereus royeni (L.) Byles & Rowley

Scattered trees on the limestone plain, abundant west of The Settlement. B. & W. [as *Cephalocereus royeni* (L.) Britt.]; D'Arcy sight record.

LYTHRACEAE

Ammania coccinea Rottb.

Weed in The Settlement. D'Arcy 5108 (MO).

COMBRETACEAE

Conocarpus erecta L.

Frequent near the sea. The silvery form was not seen. B. & W.; D'Arcy 4801 (MO); 4905 (MO).

Laguncularia racemosa (L.) Gaertn. f.

Along the south coast and plentiful around Flamingo Pond. B. & W.; D'Arcy 4802 (MO); 4917 (MO, SIU).

MYRTACEAE

Eugenia axillaris (Sw.) Willd.

Infrequent on the limestone plain. B. & W.; D'Arcy 5067 (MO, SIU); 5072 (A, MO, SIU); 5073 (MO).

RHIZOPHORACEAE

Rhizophora mangle L.

The dominant plant along the south coast in the eastern two thirds of the island. B. & W.; D'Arcy 4970 (MO).

ARALIACEAE

Polyscias filicifolia (Moore) Bailey

Cultivated for ornament. Sight record.

THEOPHRASTACEAE

Jacquinia arborea Vahl

One of the dominant shrubs on the sandy plain, also occasional on the limestone plain. "Sumba bush." B. & W. [as _J. barbasco_ (Loefl.) Mez]; D'Arcy 4795 (A, BM, C, FAU, KSC, IJ, MO); 5086 (A, BM, BR, C, FAU, LE, MO, P, SIU).

Jacquinia berterii Spreng.

Rare on the limestone plain. B. & W.; D'Arcy 2134 (FLAS); 5071 (MO).

SAPOTACEAE

Bumelia obovata (Lam.) A. DC.

Infrequent on both sandy plain and limestone plain. B. & W.; D'Arcy 4915 (MO, SIU); 5104 (A, C, IJ, MO).

OLACEAE

Forestiera eggersiana Krug & Urb.

Seen once on the limestone plain northeast of The Settlement. The plant was pistillate. D'Arcy 5135A (C, IJ, MO).

Forestiera segregata (Jacq.) Krug & Urb.

Rare on the limestone plain. D'Arcy 5074 (MO).

GENTIANACEAE

Centaurium brittonii Millsp.

"Shaded saline, sandy soil, West End." Britton & Fishlock 952 (NY).

APOCYNACEAE

Catharanthus roseus (L.) G. Don

Cultivated and escaping in The Settlement. D'Arcy 4861 (MO).

Nerium oleander L.

Cultivated in The Settlement. Sight record.

Plumeria alba L.

Very common the limestone plain. B. & W.; D'Arcy 4887 (MO, SIU).

Rauwolfia viridis R. & S.

Uncommon, roadside near airport. D'Arcy 4913 (MO, SIU).

Urechites lutea (L.) Britt.

Occasional, climbing on shrubs in most parts of the island. B. & W.; D'Arcy 2119 (FLAS); 4829 (BM, C, FAU, IJ, MO, SIU).

ASCLEPIADACEAE

Cryptostegia grandiflora R. Br.

Cultivated in The Settlement and escaping nearby. D'Arcy 4878 (MO).

Cynanchum anegadensis (Britt.) Alain

Very plentiful on the sandy plain, occasional on the limestone plain. B. & W. [as Metastelma anegadense Britt.]; D'Arcy 4809 (C, FAU, IJ, MO, SIU, US); 4973 (MO); 5087 (A, FAU, MO).

CONVOLVULACEAE

Cuscuta globosa Benth.

On Cryptostegia grandiflora in The Settlement, a single patch. D'Arcy 5109 (MO).

Cuscuta umbellata H.B.K.

Infesting most of the Portulaca quadrifida in The Settlement. D'Arcy 4902 (FAU, MO, SIU); also on D'Arcy 4909 and Fishlock 30 (see Portulaca, above).

Evolvulus arbusculus Poir.

"Occasional on the rocky plain," "rocky plain, West End," and "Rare, only observed in one place on the edge of a small cove." Britton & Fishlock 1004 (NY); Fishlock 7 (NY) [as E. squamosus Britt.].

Evolvulus bracei House

On sand or limestone behind Loblolly Bay and near The Settlement. Britton & Fishlock 1035 (NY) [as E. sericeus Sw.]; D'Arcy 4958A (C, IJ, MO); 5112C (MO, NSW); 5126 (FAU, MO).

Evolvulus glaber Spreng.

Widely scattered in local patches on limestone, sometimes in heavily grazed areas. Britton & Fishlock 1008 (NY); D'Arcy 4905 (BM, C, FAU, IJ, MO, SIU, US); 5112 (MO).

Ipomoea batatas (L.) L.

Cultivated as a food crop. Sight record.

Ipomoea fistulosa Choisy

Cultivated for ornament in The Settlement. Sight record.

Ipomoea pes-caprae (L.) R. Br.

Occasional by the sea. D'Arcy 4943 (MO).

Ipomoea triloba L.

Plentiful at the airport. D'Arcy 5118 (MO).

Jacquemontia cayensis Britt.

Plentiful climbing on shrubs on the sandy plain. B. & W.; D'Arcy 4799 (FAU, MO); 5090 (A, C, FAU, MO, P, SIU).

Jaquemontia pentantha (Jacq.) G. Don

Rare, a single patch seen on fencerow west of the airport. D'Arcy 4911 (FAU, MO, SIU).

BORAGINACEAE

Bourreria succulenta Jacq.

Scattered plants on the limestone plain. B. & W.; D'Arcy 4918 (MO, SIU); 5079 (MO, SIU).

Cordia rupicola Urb.

Scattered plants around the limestone plain. Anegada material lacks the long calyx appendages of C. bahamensis (Urb.) Millsp. but otherwise resembles the type of that name. Under C. rupicola further study might lead to recognition of infraspecific taxa for Puerto Rico, Anegada and the Bahamas. Except for its dull leaf surface, this species resembles C. lima (Desv.) R. & S. which occurs on Puerto Rico, Hispaniola and St. Croix. B. & W. [as Varronia bahamense (Urb.) Millsp.]; D'Arcy 4838 (MO); 4971 (MO); 5077 (A, FAU, MO, SIU).

<u>Heliotropium angiospermum</u> Murray

Occasional by house sites on the sandy plain. D'Arcy 4854 (MO).

<u>Heliotropium crispiflorum</u> Urb.

B. & W. [a specimen to support this record was not located at NY].

<u>Heliotropium curassavicum</u> L.

Large patches at the west of the rocky plain. D'Arcy 4882 (MO).

<u>Heliotropium microphyllum</u> Sw.

Scattered populations on the limestone plain, often growing with <u>Evolvulus bracei</u> which it superficially resembles. D'Arcy 2117 (FLAS); 4927 (A, BM, C, IJ, MO); 4957 (A, MO); 5128 (MO).

<u>Tournefortia gnaphalodes</u> (L.) R. Br.

One of the important shrubs of coastal dunes and other seacoasts. B. & W. [as <u>Mallotonia gnaphalodes</u> (L.) Britt.]; D'Arcy 4832 (MO).

<u>Tournefortia volubilis</u> L.

Occasional on the limestone plain. D'Arcy 2029 (FLAS, MO); 4912 (FAU, IJ, MO, SIU, US).

VERBENACEAE

<u>Citharexylem fruticosum</u> L.

B. & W.

<u>Clerodendron aculeatum</u> (L.) Schlecht.

Occasional on the limestone plain. B. & W. [as <u>Volkameria aculeata</u> L.]; D'Arcy 4960 (MO); 4964 (MO).

<u>Lantana camara</u> L.

Scattered plants around The Settlement. D'Arcy 4864 (MO).

<u>Lantana involucrata</u> L.

One of the dominant shrubs on the sandy plain. B. & W.; D'Arcy 4797 (FAU, IJ, MO, SCZ, SIU, US).

LABIATAE

<u>Coleus amboinicus</u> Lour.

Locally abundant on limestone just west of The Settlement. D'Arcy 4876 (MO).

Coleus scutellarioides (L.) Benth. [= Coleus blumei sensu B. & W.]

Sparingly escaped, The Settlement. D'Arcy 4984 (MO).

Ocimum basilicum L.

Cultivated for seasoning. D'Arcy 5092 (MO).

Salvia serotina L.

Plentiful around The Settlement. B. & W.; D'Arcy 2114 (FLAS); 4859 (C, FAU, IJ, MO, SIU, US).

SOLANACEAE

Capsicum annuum L. var. annuum

Cultivated in The Settlement. Sight record.

Datura innoxia Mill.

Weed in The Settlement. D'Arcy 4900 (MO).

Lycium tweedianum var. chrysocarpum (Urb. & Ekm.) C. L. Hitchc.

Plentiful on the limestone plain, ranging from prostrate forbs at the west of the plain to large thickets 1.5 m tall covering several rods of area in the eastern end of the island. B. & W. [as L. americanum Jacq.]; D'Arcy 2136 (FLAS); 4862 (BM, C, FAU, IJ, MO, SIU, US).

Physalis angulata L.

Weed by house site on the sandy plain near Pomato Point. B. & W.; D'Arcy 4851 (MO).

Physalis cordata Mill.

Locally plentiful on muddy limestone path immediately east of The Settlement. D'Arcy 5056 (BM, C, FAU, IJ, MO, NSW).

Solanum americanum Mill.

Frequent large plants along road from The Settlement to the airport. D'Arcy 5122 (MO).

Solanum elaeagnifolium Cav.

Plentiful weed around The Settlement. D'Arcy 4861 (MO, SIU).

Solanum melongena L.

Cultivated in The Settlement. Sight record.

Solanum persicaeifolium Dun.

Locally plentiful on the limestone plain; variable as to flower color. B. & W.; D'Arcy 2154 (FLAS); 4825 (MO); 4869 (MO); 4893A (MO).

SCROPHULARIACEAE

Capraria biflora L.

Common weed around The Settlement. D'Arcy 4880 (MO).

BIGNONIACEAE

Tabebuia pallida (Lindl) Miers

Occasional small copses on the sandy plain and on the limestone plain. B. & W. [as T. heterophylla (DC.) Britt.]; D'Arcy 4841 (C, FAU, IJ, MO, SIU, US).

Tecoma stans (L.) H.B.K.

A flourishing ornamental in The Settlement. Sight record.

ACANTHACEAE

Oplonia microphylla (Lam.) Stearn [= Anthacanthus spinosus]

Occasional large shrubs on the limestone plain, mostly east of The Settlement. D'Arcy 4939 (BM, FAU, MO, US).

RUBIACEAE

Borreria verticillata (L.) G.F.W. Mey.

Weed in sand behind Loblolly Bay. D'Arcy 4944 (IJ, MO).

Erithalis fruticosa L.

On the sandy plain, plentiful. B. & W.; D'Arcy 4808A (C, FAU, MO).

Ernodea littoralis Sw.

Abundant on the sandy plain. B. & W.; D'Arcy 4804 (MO); 5095 (MO).

Exostemma caribaeum (Jacq.) R. & S.

B. & W.

Randia aculeata L.

Frequent on the limestone plain. B. & W. [as R. mitis L.]; D'Arcy 4868 (MO).

Spermacoce tenuior L.

Weed in The Settlement and in the sand or limestone on the limestone plain. B. & W.; D'Arcy 4980 (MO); 5064D (MO); 5112F (MO).

Strumpfia maritima Jacq.

Forming large masses on the sandy plain and frequent along the coastal dunes. B. & W.; D'Arcy 2141 (FLAS); 4826 (A, C, FAU, IJ, MO, SIU); 4850 (MO).

CUCURBITACEAE

Cucumis anguria L.

"Rocky plain near settlement." Britton & Fishlock 1036 (NY).

Cucumis melo L.

Spontaneous near gardens, sandy plain. D'Arcy 4848 (MO).

GOODENIACEAE

Scaevola plumieri (L.) Urb.

Scattered plants by sandy coasts. B. & W.; D'Arcy 4819 (MO).

COMPOSITAE

Borrichia arborescens (L.) DC.

Small plants around Flamingo Pond. B. & W.; D'Arcy 4806 (C, FAU, MO, SIU, US).

Eclipta prostrata (L.) L.

Weed in The Settlement. D'Arcy 5105.

Gundlachia corymbosa (Urb.) Britt.

Plentiful around the island, especially on the sandy plain. B. & W.; D'Arcy 2122 (MO); 4806 (BM, C, FAU, KSC, MO, SIU, US).

Parthenium hysterophorus L.

Weed around The Settlement. D'Arcy 5066 (MO).

Pectis linifolia L.

A solitary plant seen at the airport. D'Arcy 5120 (MO).

<u>Pluchea purpurascens</u> (Sw.) DC.

"Rocky plain near settlement." Britton & Fishlock 1012 (NY).

<u>Synedrella nodiflora</u> (L.) Gaertn.

Weed in The Settlement. D'Arcy 4987 (MO); 5106 (MO, SIU).

<u>Vernonia cinerea</u> (L.) Less.

Weed in The Settlement. D'Arcy 4977 (MO); 5122B (MO).

<u>Wedelia parviflora</u> L.-Cl. Rich.

On the limestone plain. [includes W. <u>calycina</u> L.-Cl. Rich.] B. & W.; D'Arcy 2131 (MO); 4871 (MO); 4948 (C, FAU, IJ, MO, SCZ, SIU, US).

<u>Zinnia</u> sp.

Cultivated in cans in The Settlement. Sight record.

B. NON-VASCULAR PLANTS

BRYOPHYTA

<u>Barbula agraria</u> Hedw.

Encrusting surface rocks. D'Arcy s.n. (MO).

<u>Bryum microdecurrens</u> E.G. Britt.

B. & W.

<u>Hymenostomum breutelii</u> (C. Muell.) Broth.

B. & W.

CHAROPHYTA

<u>Chara</u> sp.

B. & W.

CYANOPHYTA

<u>Scytonema hofmannii</u> Ag.

Encrusting surface rocks. D'Arcy 5147 (PHILA).

LICHENES

Dermatocarpon hepaticum (Ach.) T. Fr.

Plentiful and forming small mats around shallow solution puddles on the limestone plain. D'Arcy 5063B (MINN).

Eight other lichens were reported by Britton and Wilson and the list was repeated by D'Arcy (1971a).

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THE NATURAL HISTORY OF NAMOLUK ATOLL, EASTERN CAROLINE ISLANDS

by Mac Marshall

with identifications of vascular flora

by F. R. Fosberg

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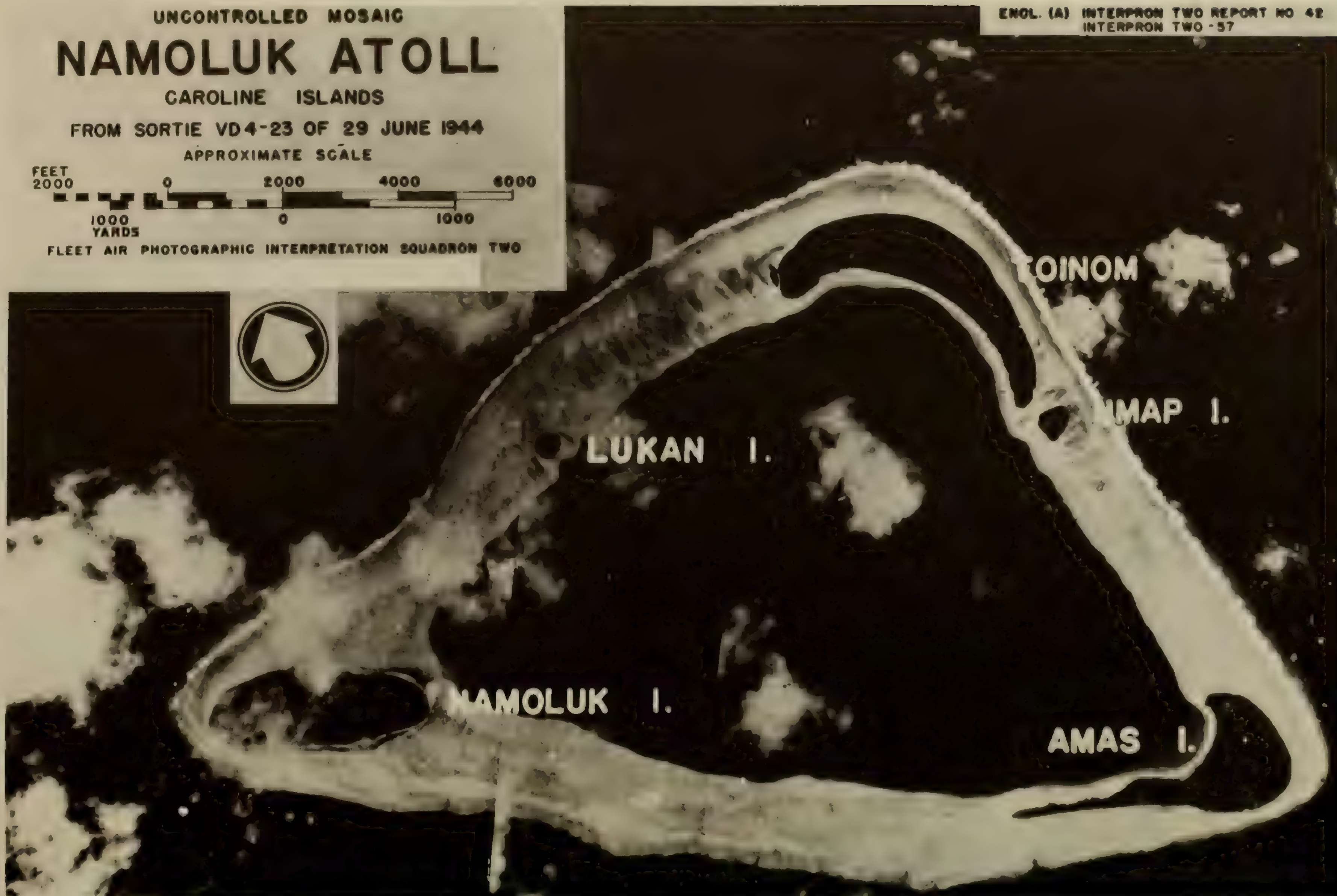

THE NATURAL HISTORY OF NAMOLUK ATOLL, EASTERN CAROLINE ISLANDS

by Mac Marshall[1]

INTRODUCTION

As of 1969, the scientific community had no general information on the natural history of Namoluk Atoll in the Eastern Caroline Islands of Micronesia. The only significant published source for the atoll was an ethnographic and linguistic account provided by the German physician, Max Girschner (1912, 1913), that contained a few brief passages on the biology and physical environment of the atoll. With this lack of basic descriptive environmental information in mind, I resolved to make observations and collections of specimens of use to other atoll scholars ancillary to an anthropological research project which I undertook on Namoluk from 1969-1971.[2] This paper is designed to fill some of the

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[1] Department of Anthropology, University of Iowa, Iowa City, Iowa 52242.

[2] Field research in cultural anthropology was conducted on Namoluk Atoll and with Namoluk persons on Moen Island, Truk, for a period of eighteen months during 1969-1971 supported by the National Institute of Mental Health (MH 11871-01 and MH 42666-01), and the Department of Anthropology, University of Washington. Funds for gathering botanical data were made available from the Bernice Pauahi Bishop Museum and the University of Hawaii (NIH Grant No. GM-15198) through the kind assistance of Douglas Yen. Preparation of this manuscript was facilitated by an Old Gold Summer Faculty Research Fellowship from the Graduate College, University of Iowa. I am greatly indebted to these sources of financial support. I would also like to express my appreciation to Sarel R. Agrippa for maintaining the meteorological observations in my absence from June to December 1970, to Sapuro I. Kouch, Kichi Lippwe and Kino S. Ruben for assistance in gathering and preparing the plant collections, to F. R. Fosberg for material assistance and encouragement, and to John Tandarich for technical help in preparation of the photographs for publication. During the period of research the de facto population of Namoluk Atoll fluctuated between 250 and 300 persons, depending upon how many happened to be away in the port town on Moen Island, Truk, or elsewhere at a given moment. The most recent census figures available from the Trust Territory indicate that this number has remained stable through 18 September 1973 (U.S. Trust Territory of the Pacific Islands 1974), with 263 persons reported on Namoluk Atoll at census time. The total living population of 'Namoluk citizens' regardless of location numbered 416 on 1 January 1973. At present, the entire human population of the atoll resides on Namoluk Islet; Amwes Islet, which formerly supported a separate community, has not been permanently inhabited since its populace was decimated by an epidemic in the late 1930s. The reader interested in further details on Namoluk demography is referred to an extended treatment of this subject (Marshall 1975).

gaps in our knowledge of the natural history of Namoluk by summarizing and reporting the information so gathered through August 1971. With the exception of a brief note on avifauna (Marshall 1971), these are the first systematic environmental data to be presented for the atoll.

Until archaeological investigations are undertaken, the prehistory of Namoluk must remain conjectural. Although we lack any reliable estimate of the time depth of human habitation on the atoll, we are fortunate to have a few ethnohistorical records that offer some sense of the atoll's early contact with the West.

The first Westerner to sight Namoluk was an American whaling captain, Richard Macy, aboard the Harvest in 1827 (Day 1966:171; Sharp 1960:217). Less than a year later in 1828, a Russian scientific expedition under the command of Fedor Lütke visited Namoluk. Although Namoluk men boarded Lütke's ship to trade, none of the ship's company put ashore (Lütke 1835:88-91).

Only scattered records exist of vessels sighting or calling at Namoluk during the 1830s and 1840s. Benjamin Morrell, captain of the ship Antarctic out of Stonington, Connecticut, passed close by Namoluk in 1830, evidently without landing (Morrell 1832:388-389). Three years later an American whaler, the Hashmy under Captain Harwood, called at Namoluk, and an extract from the Hashmy's log recounts what is believed to be the first arrival of Westerners on the atoll (Ward 1967:3-4).

By the 1840s traders began venturing into the Eastern Carolines, although relatively few historical documents seem to have survived this era. The bark Zotoff out of Salem, Massachusetts, skippered by a trader named Captain Wallis, sailed past Namoluk without heaving to on 7 June 1846 while en route from Manila to Fiji (Wallis 1851:195). In July of the same year the trader Andrew Cheyne called at Namoluk aboard the Naiad, and he commented that the islets were "covered with cocoa-nuts and bread-fruit trees" (Cheyne 1852:129).

From the 1840s there follows a thirty year hiatus for which no known historical materials pertaining to Namoluk have been found. In rapid succession during the 1870s and early 1880s, however, Protestant missionaries and resident traders came to Namoluk. The Reverend E. T. Doane stopped briefly at Namoluk in 1874 aboard the mission vessel Star (Doane 1874:204), and on 1 December 1879 a young Ponapean missionary couple took up residence on the atoll (Missionary Herald 1880:175). The British trading schooner Rupak did not land a party when she reached Namoluk on 19 April 1875 because she could locate no pass through the reef (Robertson 1877:51-52), but despite the hazards of Namoluk's barrier reef, a young American trader, George Barrows, settled briefly on the atoll in 1880, and he was succeeded shortly thereafter by a Dutch trader named "Jacob" in 1881 (Westwood 1905:119, 131). Unfortunately, we lack records for many of the ships that must have called at Namoluk during this period, although we do know that the Henderson and MacFarlane trading vessel Belle Brandon, Captain Harris, visited the atoll in early 1880 (Dana 1935:100). From this time on,

Namoluk's contact with the outside world increased steadily, and contact has been more or less continuous under the German, Japanese, and American colonial administrations.

PHYSICAL DESCRIPTION

Namoluk is a small, triangular-shaped coral atoll located at 5° 55' north latitude and 153° 08' east longitude, approximately 200 kilometers southeast of Truk in the Eastern Caroline Islands. Namoluk's nearest neighbors are Etal Atoll, lying some 56 kilometers to the southeast, and Losap Atoll situated 105 kilometers to the northwest.

Roughly 1.5 kilometers on each side, Namoluk's reefs completely encircle a lagoon of about 7.5 square kilometers. Reference to plate 1 shows that the atoll is divided into five islets: Namoluk, Lukan, Tŏinom, Umap, and Amwes (also spelled Amas). The total land area of these five islets is .834 square kilometers or around 83 hectares, and is distributed as follows: Namoluk (31 hectares), Amwes (28 hectares), Tŏinom (21 hectares), Lukan (1.5 hectares), and Umap (1.5 hectares).

It is of geological interest to note that Lütke (1835) circumnavigated the atoll early in 1828 and reported only four islets. Given the reliability accorded Lütke's observations by historians, it seems unlikely that this number is in error. Less than twenty years later, another reliable observer of the Pacific scene visited Namoluk and mentioned that the atoll consisted of five islets (Cheyne 1852:129). On the basis of this evidence, it seems probable that Umap and Tŏinom Islets separated into two distinct landforms sometime between 1828 and 1846. Perhaps the sea broke through during a severe typhoon of which we have no record (see plate 2).

Namoluk's lagoon, which drops to a depth of 42 fathoms at its center, is among the deepest in the Pacific, and the ocean waters surrounding the atoll reach depths well over 400 fathoms only 1.5 kilometers offshore.

Sometime between June 1944, when the U.S. Navy made an aerial photomosaic of Namoluk (plate 1), and October 1969, when the research reported here began, an "unnamed" sixth islet to which Bryan (1971) makes reference merged with Tŏinom and now forms the northwest tip of that islet. Actually, this piece of land (named Chä) was never a separate islet at all, but rather a sandbar covered with scrub vegetation (especially Pemphis acidula), and connected to the northwest end of Tŏinom. At high tide this sandbar was separated from Tŏinom by a shallow channel of water; at low tide it was joined to Tŏinom, and a small salt-water pool formed between them. Informants recall this pool as an effective natural fish trap.

REEFS AND CURRENTS

Contrary to the map of Namoluk Atoll presented in Bryan (1971), which is reproduced from U.S. Hydrographic Office Chart 5425, taken in turn from a Japanese sketch survey done in 1924, there is no boat passage or break in the reef as shown between Amwes and Namoluk Islets. There are several natural surge channels through which outrigger canoes can make their way (often with difficulty), and one of these -- located near Namoluk Islet on the southwest side -- has been artificially deepened by blasting to permit outboard motorboats to pass at high tide. This channel was first widened and deepened by blasting as part of a governmental reconstruction program on Namoluk following Typhoon Phyllis in 1958; additional work was carried out in 1973. Even so, passage through this channel requires a tortuous one-quarter mile trip from the beach to open sea.

During the research period, three bottles containing messages were found on the northeast side of Töinom Islet (which is the direction from which the prevailing tradewinds blow). The information on these notes may be of interest to students of Pacific currents, and the relevant data are summarized below (see table 1).

METEOROLOGY

A daily weather log was maintained on Namoluk for a nineteen month period from 1 January 1970 to 31 July 1971. A minimum-maximum thermometer and a rain gauge were read and reset every twenty-four hours at 6:30 A.M., and the resulting data are presented in table 2.

Namoluk is on the eastern edge of the typhoon belt in the western Pacific, and as such the atoll is visited by destructive storms only infrequently. The typhoon of 27 March 1907 that devastated the Lower Mortlock Islands, causing over 200 deaths there, did not strike Namoluk severely (Anonymous 1907:864), although older informants recall that heavy seas washed inland on Amwes Islet. Likewise, it does not appear that the typhoon of early December 1935 did much damage to Namoluk (U.S. Navy 1944:6). On 24 and 25 May 1958, however, Typhoon Phyllis, packing winds over 100 miles per hour, passed just north of Namoluk causing extensive damage. In brief, physical destruction was as follows:

> Practically 75% of all trees were completely uprooted. The remaining 25% were mere stumps sticking 15 or 20 feet into the air. The damage to homes and community buildings was complete. Fortunately only one person was lost during the storm. Destruction of the islands' canoes was complete (Davis 1959a:13).

In the aftermath of Phyllis, almost 100 percent subsistence was given Namoluk people by the Trust Territory government in the form of rice,

flour, and C-rations for well over a year. A gardening and coconut replanting program was begun on the atoll, and materials were provided by the government to rebuild homes and community buildings. Before the typhoon a few breadfruit trees grew on Lukan and Umap Islets; since 1958 there have been none. Before the typhoon more than 100 pigs roamed and rooted about on Amwes Islet; since 1958 the pig population on the atoll has not exceeded forty animals. It is small wonder that Typhoon Phyllis has become an indelible time marker for Namoluk people.

In February 1970 and April 1971, tropical storms Nancy and Amy blew over Namoluk causing some damage to plants. Amy later grew into a typhoon and caused over four million dollars worth of damage on Truk proper and on the atolls to the north of Truk. Most recently, a <u>tsunami</u> hit Namoluk on 17 January 1972, sweeping inland to the taro swamp and doing considerable harm to taro and other plants not tolerant of salt water (Agrippa 1972).

NON-AVIAN TERRESTRIAL VERTEBRATES

In a brief discussion of Namoluk's fauna, Girschner (1912:126) wrote:

> There are also few animal species. Mammals: the flying dog, rat, cat, pig (now extinct because of the damage it did to plants) and the domestic dog, which was also gotten rid of fairly recently because of its biting habits ... Reptiles: four kinds of lizard and occasionally (sea) turtles (the soup and carret varieties) (translation by Diana Maughan).

To a large degree this list remains descriptive of Namoluk's nonavian terrestrial fauna today.

Mammals presently found on the atoll include the "flying fox" or fruit bat (<u>pwā</u>) (Girschner's "flying dog"), the cat (<u>katu</u>), the pig (<u>pik</u>), two species of rat (<u>maniwel</u>), and as of 1972, the dog (<u>kolek</u>). Of these mammals, only the fruit bat (Pteropus sp.) occurs on all of the islets.

Dogs were not kept on Namoluk from 1963 to 1972 because of their uncleanliness and the trouble they caused among people. Correspondence with persons on the atoll reveals that dogs were reintroduced from Etal Atoll and Truk during 1972. Judging from Girschner's comment (1912:126), the keeping of dogs has been a cyclic phenomenon on Namoluk; a similar cyclical pattern for keeping dogs has been reported to me by Vern Carroll for Nukuoro Atoll.

The cat population of approximately fifty animals is concentrated heavily on Namoluk Islet; based on observations and informants' statements, fewer than twenty semi-feral cats are presumed to live on Töinom and Amwes, and Lukan and Umap have no cats. In February 1971 there were twenty-seven pigs on the atoll--all on Namoluk Islet where they

are kept penned or tethered. Rats occur in great abundance on the three largest islets, and it is common to observe them scurrying about in broad daylight. Trapping efforts in 1971 give credence to local stories claiming Lukan Islet to be rat-free. Detailed observations on man-animal interaction, and the trapping of more than 650 rats were accomplished as part of a seroepidemiologic study of toxoplasmosis carried out in 1970 and 1971 (Marshall 1972; Wallace, Marshall and Marshall 1972), and no rats were captured on Lukan Islet although consistently high catches were made everywhere else the traps were set. Rats do occur on Umap Islet, but interestingly all sixty-three of those trapped there during five days of trapping were Rattus rattus. This datum is striking because of all the rats live trapped on the atoll in 1971, 64 percent (420/658) were Rattus exulans, and only 36 percent (238/658) were Rattus rattus. No satisfactory explanation is at hand for why Rattus exulans evidently has failed to colonize Umap Islet.

Nine lizard species were collected on Namoluk Islet in June and July 1971 and placed in the Bernice P. Bishop Museum, Honolulu, Hawaii. Through the kind assistance of Alan C. Ziegler, Vertebrate Zoologist at the Bishop Museum, these specimens have been identified by Richard G. Zweifel of the American Museum of Natural History in New York. The collection may be taken as representative but not exhaustive because the sample size was relatively small (N=13), and specimens were acquired from only one of the five islets in the atoll. At least one species of gecko is known to be missing from the collection since it repeatedly eluded capture. This was a large variety (approximately 300 millimeters) that lives in the crown of coconut palms and has been observed eating smaller geckos.

All geckos are called pacharou (literally 'sticks to the rafters') on Namoluk, and the following four species are known to be present: (1) Cyrtodactylus pelagicus (BBM-5470), (2) Perochirus sp. (BBM-5477), (3) Gehyra mutilata (BBM-5478, BBM-5481), and (4) Lepidodactylus lugubris (BBM-5479, BBM-5480).

The Cyrtodactylus gecko was observed at night only on perhaps a half a dozen occasions. Whenever it was seen, it was always on or near the ground, and it quickly scurried into a hole when approached. All of the remaining species of geckos were seen nightly, and were ubiquitous in and on houses and on the trunks and in the crowns of coconut palms. All of the specimens taken were captured at night either in our corrugated tin outhouse or on the outside cement walls of our house. Generally, geckos became active about 4:30 P.M.; they were not to be seen outside during the day unless disturbed from hiding. Occasionally, geckos were observed feeding indoors during the day on ripe bananas, gnats and flies, and spilled cooking oil.

Skinks are very numerous on all of the islets throughout the underbrush and climbing on tree trunks (especially coconut and breadfruit trees). The five species listed below have been identified for Namoluk: (1) Eugongylus albofasciolatus (BBM-5469), (2) Lamprolepsis smaragdina

(Dasia auct.) (BBM-5471), (3) Emoia cyanura (BBM-5472, BBM-5473), (4) Emoia boettgeri boettgeri (BBM-5474, BBM-5475), and (5) Emoia caeruleocauda werneri (BBM-5476).

Namoluk people refer to the Eugongylus skink as kuel en le mweal 'lizard that hides in the helmut shell cooking vessel', and this species is much detested because of its large size and fearsome appearance. Furthermore, kuel en le mweal play a role in black magic which may help explain the general repugnance toward them: it is believed that to dream one has been bitten by one of these skinks is a sign that one has been sorcerized. Biggest among the lizards on the atoll, and usually slow and methodic of movement, Eugongylus can run rapidly when alarmed. Eugongylus are active during the day, and I have observed them feeding on ants and garbage while rummaging about in dead leaves and coconut fronds. These skinks make their home in holes in the ground under fallen logs and rocks. The Lamprolepis skink, called puwaroch locally, is extremely plentiful in the woods, and normally is to be found scaling the trunks of breadfruit trees. The three species of Emoia skinks are referred to collectively as puwal by Namoluk people. Although these species do climb trees on occasion, they are mostly seen running about in the underbrush and on fallen logs. The large monitor lizard (Varanus indicus) that was introduced by the Japanese for rat control on Truk and in the Lower Mortlock Islands (Etal, Lukunor, and Satawan Atolls) was never brought to Namoluk; its local name is kaluf. There are no snakes, land tortoises or amphibians on the atoll.

OTHER NON-AVIAN FAUNA

Both the green sea turtle (Chelonia mydas) (Wounamon), and the hawksbill turtle (Eratmochelys imbricata) (wounlele) frequent the lagoon and surrounding waters, with the former species being far more common. The turtles feed on extensive beds of "turtle grass" growing underwater near the lagoon shore, and now and again they come ashore to lay their eggs on the seaward side of Amwes Islet. Turtles of any size are killed whenever possible for their highly-prized meat and for their shells which are a valuable item of trade.

Several terrestrial decapod crustacea are plentiful on the atoll and form an important component of the land fauna. The coconut crab (Birgus latro), known to Namoluk people as manta, and a good-sized burrowing species--probably Cardisoma sp.--called rakum, are part of the regular human diet. Hermit crabs (Coenobita sp.) crawl nearly everywhere.

AVIAN FAUNA

A short research note on the avifauna of Namoluk Atoll already has appeared (Marshall 1971). The purpose of this section is to expand the earlier account with additional information.

Fourteen families of birds containing twenty-one species have been recorded for Namoluk in addition to two other families that formerly were represented but now have died out. Of the fourteen families, seven (containing eleven species) are resident breeders on the atoll, four families (containing six species) are regular visitors to Namoluk, and another three families (with four species) are seen occasionally on the atoll. The Laridae comprise the most numerous family on Namoluk both in total numbers and number of species. Next most numerous are the Scolopacidae as regular migratory visitors.

In 1912, Girschner reported that:

> Twenty-two birds were named [by Namoluk people], including the fruit dove (*Carpophaga oceanica*), which no longer existed at the time, but was ostensibly killed by the missionaries, a bright starling (*Calornia pacifica*), not very popular with the natives because it eats their bananas, papayas, etc., a kind of reed thrush (*Calamoherpe syriax*), the only bird with a pleasant song, a lovely red and black honeyeater (*Myzomela rubrata*), two herons, two sandpipers, two marsh birds, one kind of wild duck, various sea birds making their homes there for varying lengths of time, and finally the chicken. Since the typhoon of 1905, which devastated Ponape, the small parrot from that island lives on Namoluk, forced there by the storm (translation by Diana Maughan) (Girschner 1912:125-126).

Later, in a list of Namoluk vocabulary, Girschner gives the Namoluk names for twenty-one kinds of birds (1913:182), and from these two bits of information it is possible to identify positively sixteen species still to be found on Namoluk in 1969-1971. Although Girschner mentions "a bright starling" when discussing the twenty-two birds named by his informants, he later fails to provide the native name for this bird: *mwi*. This accounts for the discrepancy between his statement that there were twenty-two named birds (1912:125), and his list of only twenty-one bird names (1913:182).

In the annotated list of birds presented below, those mentioned by Girschner that can be identified are so noted. Namoluk names are given given in parentheses after the common name; scientific identifications follow Baker (1951).

ANNOTATED LIST OF NAMOLUK BIRDS

PROCELLARIIDAE

WEDGE-TAILED SHEARWATER (*machukou*) *Puffinus pacificus*

Occasional visitor.

Common in the vicinity of Truk's high islands, I saw this species only once at Namoluk when a flock of ten birds accompanied the arrival of a government field trip vessel from Truk on 17 May 1971. The birds stayed all morning, skimming the waves and soaring up into the air, providing ample opportunity for positive identification. This bird is not mentioned in Girschner (1912, 1913), and shearwaters were never observed to land on the atoll.

PHAETHONTIDAE

WHITE-TAILED TROPICBIRD (uuk) *Phaethon lepturus*

Resident breeder.

The population of tropicbirds on Namoluk is estimated not to exceed fifty birds, all of which nest in breadfruit trees (frequently in clumps of *Asplenium nidus*) on Amwes and Töinom Islets. Noted by Girschner (1913:182) by its local name, this bird is eaten by humans as often as it can be caught. The technique for capture is to note an adult sitting on a clutch of eggs, and for one person to set up a terrible racket at the base of the tree. The noise so frightens and distracts the bird that another person is able to climb up the opposite side of the tree and snatch the bird from its nest (cf. Bayliss-Smith 1972 for a similar report for Ontong Java).

SULIDAE

BROWN BOOBY (apwang) *Sula leucogaster*

Occasional visitor.

A group of four birds was spotted just off the southwestern side of the atoll on 5 March 1970. Apparently, they had accompanied a ship which had arrived early that morning. A lone specimen was seen flying from the southeast to the northwest across the lagoon on 6 May 1971, soon after Typhoon Amy had passed through Truk District. While this species was noted by Girschner (1913:182), these were the only occasions that I observed boobies anywhere in the vicinity of Namoluk. I never saw them alight on the atoll.

FREGATIDAE

GREATER FRIGATEBIRD (asaf) *Fregata minor*

Regular visitor.

Said by informants to breed in the Lower Mortlocks where they are reportedly sometimes kept as pets, these majestic birds do not nest on Namoluk. Usually they are seen soaring high in the sky preceding stormy weather, and none was ever observed by me to land on the atoll.

They were mentioned by Girschner (1913:182) who also noted that a frigatebird wing was stuck in the hair of the makal 'atoll chief' at his investiture (1912:162). Frigatebirds were spotted several times a month throughout the year.

LARIDAE

BLACK-NAPED TERN (arar) — *Sterna sumatrana*

Resident breeder.

I estimate the population of these terns at fifty to 100 birds. They nest on sandbars and exposed reef outcroppings, and were seen almost daily usually flying in pairs. Girschner (1913:182) notes them by their Namoluk name.

CRESTED TERN (arafao) — *Thallasseus bergii*

Resident breeder.

Scanning the shallows and then plunging suddenly into the water to emerge with fish dangling from their beaks, these terns are among the more spectacular birds to watch on the atoll. Their numbers are not large -- estimated at no more than fifty birds -- and they nest on the uninhabited islets. Crested terns were mentioned by Girschner (1913: 182).

BROWN NODDY (kokok) — *Anous stolidus*

Resident breeder.

Easily the most abundant bird on the atoll, these noddies particularly like to nest in pandanus and in the crowns of coconut palms. My wife and I raised two as pets while resident on Namoluk. Brown noddies are eaten frequently by people who kill them with slingshots or by well-aimed rocks. Although this species was not cited by Girschner by its local name, it is inconceivable that it was not present in 1910. It appears likely that what Girschner recorded as kirekak (1913:182) is what now is called kokok on Namoluk, especially since the word kirekak is no longer in use.

BLACK NODDY (resh) — *Anous tenuirostris*

Resident breeder.

Next to the brown noddy and the Micronesian starling, black noddies rank third in abundance on the atoll. They nest in breadfruit trees and are regularly captured for food. One was raised as a pet by my wife and me. Cited by Girschner (1913:182) as ras, black noddies are particularly well established on Amwes Islet.

WHITE OR FAIRY TERN (ekiek) *Gygis alba*

Resident breeder.

Mixed flocks of feeding fairy terns and noddies are used by Namoluk fishermen as indicators of probable schools of tuna, and the flocks of birds are followed by canoes and motorboats in pursuit of their quarry. Fairy terns number well over 700 birds and they commonly nest on the bare branches of breadfruit trees on the three largest islets. They were listed as present by Girschner (1913:182), and my wife and I acquired one as a chick which we kept as a pet the entire time that we lived on the atoll. In addition, we fed and released another fairy tern chick when it was old enough to fly. After the two species of noddy and the starling, fairy terns are guessed to rank fourth in abundance on the atoll.

ARDEIDAE

REEF HERON (ŏrŏ) *Egretta sacra*

Resident breeder.

Usually seen alone or sometimes in pairs, these striking white birds nest on all of the uninhabited islets. Nests were noted both in lagoon strand vegetation and in pandanus trees. Reef herons have been tamed and kept as pets by Namoluk people in the past, and informants assert that they eat skinks and geckos along with their more usual diet of fish. I estimate that there are no more than twenty-five to thirty of these birds on the atoll. They are mentioned twice by Girschner (1912:126, 1913:182).

ANATIDAE

AUSTRALIAN GREY DUCK (rang) *Anas poecilorhyncha*

Occasional visitor.

This bird was not seen by me although Girschner mentions it in two places (1912:126; 1913:182). Informants report that the ducks come singly or in pairs to the main taro swamp on Namoluk Islet, and several different people reported having seen them at various times during the late 1960s.

PHASIANIDAE

DOMESTIC FOWL (malok) *Gallus gallus*

Resident breeder.

This is the only bird on Namoluk known to have been brought to the atoll by human agency. There were approximately 450 fowl on Namoluk Islet in

1971, along with a small undetermined number gone wild on Amwes and Töinom. Several different types are named and recognized locally, including pweshepwesh 'white', magalegal 'mixed colors', parapar 'red' (referring to Rhode Island red stock introduced from the Department of Agriculture on Truk), and sapan literally 'Japan', a grey, mottled variety. Nearly every domestic unit owns several fowl, and chickens constantly forage in and around people's houses. Chickens are identified as malokemwän 'rooster', lisinger 'hen', and lisiup 'chick'. While chicken flesh is a prized feast food, few people on the atoll consume hen's eggs.

CHARADRIIDAE

PACIFIC GOLDEN PLOVER (kiling) *Pluvialis dominica*

Regular visitor.

The cry of the golden plover is familiar to every child on Namoluk as it is a regular winter visitor. Girschner (1913:182) mentions the plover, and a local story was related to me about where the plovers go when they leave Namoluk in the late spring. According to the story, the plovers fly up into the sky, higher and higher, until they reach heaven. There they lay their eggs. Once laid, the eggs immediately begin falling toward earth, and by the time they near the ground they have hatched into young golden plovers fully capable of flight and of finding their way once again to Namoluk's beaches.

SCOLOPACIDAE

WHIMBREL (liakak) *Numenius phaeopus*

Regular visitor.

Normally feeding in solitaire by dipping their long, gracefully curved beaks into exposed sand flats at low tide, these birds were present on Namoluk throughout the winter months and as late as mid-June. Whimbrels were listed by Girschner (1913:182).

AMERICAN WANDERING TATTLER (ilil) *Heteroscelus incanum*

Regular visitor.

Tattlers were observed almost daily from October to May running along the shore -- especially among exposed coral boulders. Normally, tattlers were found alone or in pairs. Girschner (1913:182) mentioned them by their Namoluk name.

RUDDY TURNSTONE (urupap) *Arenaria interpres*

Regular visitor.

Skittering along the sand in groups of from two to twenty birds,

turnstones spend their winters searching Namoluk's shoreline for food. From Girschner's report (1913:183), they were also present in the early 1900s.

COMMON SANDPIPER (maninkapuchupuch) Actitus hypoleucos

Occasional visitor.

According to informants this species is infrequently encountered on Namoluk. I observed a single specimen at a distance of about fifteen meters on 17 July 1971, and at first I mistook it for a turnstone. My companion immediately corrected me and gave me the bird's correct Namoluk name. The sandpiper was feeding by itself right along the wave line on the ocean side beach, dipping its bill into the sand. Its back was greyish and its belly was white; closer inspection showed it to be smaller than a wandering tattler with a softer cry and a slightly shorter bill. I saw this species on Namoluk only once, and it was not recorded by Girschner.

CUCULIDAE

LONG-TAILED NEW ZEALAND CUCKOO (likapilei) Eudynamis taitensis

Regular visitor.

I did not observe this bird, although I heard it twice on Namoluk Islet, and it was seen by other persons on Toinom during my residence. Apparently, it passes through Namoluk on migration to and from its regular breeding grounds in New Zealand (cf. Baker 1951:215). The cuckoo was not mentioned by Girschner.

SYLVIIDAE

NIGHTINGALE REED WARBLER (lishok) Acrocephalous luscinia

Resident breeder.

Identified by Girschner (1912:126, 1913:182) as Calamoherpe syriax, this bird was observed by me daily. It feeds heavily on insects, and may be presumed to occur on all five islets. Of the three wild resident breeding land birds (starling, honeyeater, and warbler), the warbler is least abundant. Even so, I guess their population to be between 400 and 500 for the atoll.

STURNIDAE

MICRONESIAN STARLING (mwi) Aplonis opacus

Resident breeder.

This glossy, black, inquisitive bird with a bright yellow eye is the most prolific and bold of Namoluk's land birds, and I estimate it to

be second in numbers only to the brown noddy. Nearly everywhere one goes in the brush on the atoll, a mwi tags noisily along. They are good mimics, and contrary to Girschner's assertion that the reed warbler is the only Namoluk bird "with a pleasant song," Micronesian starlings are capable of fine singing. My wife and I raised a young starling as a pet and often sat entranced at its virtuosity when it would launch into five minutes of uninterrupted whistles, trills, and warbles. Girschner (1912:125-126) identified the starling as *Calornia pacifica*. These birds usually make their nests in pandanus and coconut trees, and they feed predominantly on fruit, notably on bananas, papayas, *Morinda citrifolia*, *Crateva speciosa*, and *Eugenia sp.* Our pet also enjoyed fresh raw fish, coconut meat, and ants, and along with his wild counterparts he was particularly fond of banana blossoms. Children hunt starlings with slingshots and eat them when they are successful.

MELIPHAGIDAE

CARDINAL HONEYEATER (*liteikepar*) *Myzomela cardinalis*

Resident breeder.

These, the most beautifully colored of Namoluk's birds, were observed on all five islets; Girschner lists them as Myzomela rubrata (1912:126, 1913:182). They appear to feed almost entirely on nectar, and they are especially partial to banana blossoms. Honeyeaters are eaten by people only rarely.

COLUMBIDAE

MICRONESIAN PIGEON (*lisoam*, *witiwit*, *manekan*) *Ducula oceanica*

Extinct breeder.

Girschner (1912:125) reports that this bird (which hé identified as *Carpophaga oceanica*) formerly existed on Namoluk, but had been exterminated prior to his visit. Pigeons are good to eat, and probably were killed off as a result of the introduction of firearms by traders in the 1880s and 1890s before the German administration confiscated such weapons. The species has not reestablished itself on Namoluk, although reportedly it still occurs in the Lower Mortlocks (Nason, personal communication).

PSITTACIDAE

PONAPE LORY (no Namoluk name) *Trichoglossus rubiginosus*

Extinct breeder.

According to Girschner (1912:126), this species was blown to Namòluk in a typhoon in 1905, and apparently it still occurred on the atoll at the time of his visit. There are no lories at present on Namoluk nor can anyone alive on the atoll in 1971 remember seeing them.

Besides mentioning the Micronesian pigeon and the Ponape lory, Girschner (1913:182) provides the Namoluk names for three other species that no longer are found on the atoll. By the names Girschner gives, none of my informants could describe these three species. This is probably a result both of vocabulary changes and of possible alterations in the avifauna during the sixty years intervening between Girschner's research and my own. Despite these slight discrepancies, however, one is struck by the remarkable stability of the bird species found on Namoluk during the twentieth century.

"A small type of heron" (erenshuumenwo) (Girschner 1913:182) can be only one of three possibilities, assuming the accuracy of reports contained in Baker (1951). Either the "small heron" was the black-crowned night heron (Nycticorax nycticorax), the rufous night heron (Nycticorax caledonicus), or the Chinese least bittern (Ixobrychus sinensis). All three of these species are reported for Truk (Baker 1951). On the basis of the size clue alone -- especially since Girschner's size comparison is presumably with the reef heron -- I would presume the Chinese least bittern to be the likeliest candidate for the bird Girschner records as erenshuumenwo.

A second bird mentioned by Girschner that no longer is found on Namoluk is "a small black and white bird" for which he gives the name lipukepuk. A study of Baker (1951) reveals only a single likely possibility for this species: Lonchura nigerrima, the black-breasted weaver finch. This finch is largely black and white, of small size, and is known from Ponape and possibly from Truk.

Finally, a "sea bird" named lishinirin matau is mentioned by Girschner (1913:182); I have absolutely no idea what this bird might be.

My informants in 1970-1971 named a seabird not listed by Girschner and unseen by me which I have been unable to identify. The Namoluk name is sapal, and it is described by people on the atoll as a dark-colored, blunt-winged, gliding seabird about the size of Anous tenuirostris (a petrel?). Its most prominent characteristic, stressed to me over and over again, is that it is always seen at sea and never ventures on land. In connection with this is a short story which not only "explains" this behavioral quirk, but also carries a message for its listeners emphasizing the importance of helping and sharing with others -- a major cultural value on Namoluk. The story notes that the ghost-man named Mweriker who was king of all the fish and birds kept his canoe in a canoe house in heaven. One day he called all of the fish and birds to come help him move his canoe from heaven down to the ocean. All of the fish and birds in the world came to help except two: a small minnow called til and a seabird named sapal. When Mweriker learned that these two had failed to assist him, he became very angry, and he decreed that henceforth all other fish and birds would feed upon til whenever they came upon them, and that the sapal was doomed never to set foot on land again. Mweriker decreed that should the sapal have the temerity to alight on dry land it would immediately die. This explains why, to this day, the sapal is never seen on land and why the

til is devoured by all other fish and birds.

MARINE MOLLUSKS

A private collection of marine mollusk shells numbering over 400 specimens was made while on Namoluk. Discounting those cases where a given species is duplicated, I have identified approximately three-fourths of this collection using Abbott and Zim (1962). It must be emphasized that this represents only a portion of the total molluskan reef fauna of Namoluk. No effort was made to collect every species, and the collection is biased in favor of the more attractive shells to be found. Nevertheless, it is felt that the preliminary list given below may be of some interest to Pacific malacologists.

Of the sixty-seven species that I have been able to identify, six are exploited as edible shellfish by people on the atoll: Nerita polita, Lambis lambis, Bursa bubo, Charonia tritonis, Tridacna gigas, and Tridacna noae. The latter three species are eaten regularly, whereas the former three are consumed only irregularly.

Several mollusk shells have had or continue to have important uses in Namoluk culture. Tiger cowries (Cypraea tigris) with the crown of the shell cut away are used by women as effective scrapers for removing the outer skin of breadfruit, and from this tiger cowries derive their Namoluk name: pwil en mei literally 'breadfruit shell'. The horned helmut (Cassis cornuta) does not grow on Namoluk but Namoluk people used to import these shells from other atolls to be hollowed out and used as cooking vessels called mweal. With the easy availability of metal and glass containers today, helmut shells no longer are used in this way. The bull mouth helmut (Cypraecassis rufa), which is scarce on Namoluk, is employed in a manner similar to the horned helmut as a mixing receptable for local herbal medicines. Two unidentified species of the family Spondylidae are found on Namoluk (Girschner [1912] identifies these as Spondylus flabellum Reeve and Spondylus rubicundus Reeve), and the one with a reddish-orange lip was sought by divers in precolonial times to make faulam 'valuable orange shell disks' which were polished, strung, and used as an important item of trade and decoration (Girschner 1912:134). Finally, as on other Pacific atolls before the introduction of iron, shells were shaped into tools. On Namoluk, the marlinspike (Terebra maculata) and the giant clam (Tridacna gigas) were fashioned into adze blades. The marlinspike became the blade of the kulukul (literally 'spinning adze' because the blade could be rotated), and the giant clam was transformed into sele 'flat chopping adze'. Examples of these two kinds of adze blades from surface archaeological collections I made on Namoluk have been placed in the Thomas Burke Memorial Washington State Museum, Seattle, Washington.

PRELIMINARY CHECKLIST OF NAMOLUK MARINE MOLLUSKS

	THAIDIDAE
SETUM ROCK SHELL	*Nassa serta*
	HALIOTIDAE
BEAUTIFUL ABALONE	*Haliotis pulcherrima*
	TROCHIDAE
MACULATED TOP	*Trochus maculatus*
	TURBINIDAE
TAPESTRY TURBAN	*Turbo petholatus*
	NERITIDAE
POLITA NERITE	*Nerita polita*
	CERITHIIDAE
GIANT KNOBBED CERITH	*Cerithium nodulosum*
	STROMBIDAE
BUBBLE CONCH	*Strombus bulla*
HUMPED CONCH	*Strombus gibberulus*
SILVER CONCH	*Strombus lentiginosus*
BLOOD-MOUTH CONCH	*Strombus luhuanus*
COMMON SPIDER CONCH	*Lambis lambis*
GIANT SPIDER CONCH	*Lambis truncata*
	CYPRAEIDAE
PACIFIC DEER COWRIE	*Cypraea vitellus*
GOLD-RINGER	*Cypraea annulus*
LYNX COWRIE	*Cypraea lynx*
TIGER COWRIE	*Cypraea tigris*
ARABIAN COWRIE	*Cypraea arabica*

EGLANTINE COWRIE	_Cypraea eglantina_
RETICULATED COWRIE	_Cypraea maculifera_
EYED COWRIE	_Cypraea argus_
MOLE COWRIE	_Cypraea talpa_
ISABELLE COWRIE	_Cypraea isabella_
CARNELIAN COWRIE	_Cypraea carneola_
TORTOISE COWRIE	_Cypraea testudinaria_
HUMP-BACK COWRIE	_Cypraea mauritiana_
SNAKE-HEAD COWRIE	_Cypraea caputserpentis_
ERODED COWRIE	_Cypraea erosa_
MAP COWRIE	_Cypraea mappa_
NUCLEUS COWRIE	_Cypraea nucleus_
CHICK-PEA COWRIE	_Cypraea cicercula_
MONEY COWRIE	_Cypraea moneta_

CASSIDIDAE

VIBEX BONNET	_Casmaria vibex_
BULL MOUTH HELMUT	_Cypraecassis rufa_

BURSIDAE

GRANULATED FROG SHELL	_Bursa granularis_
GIANT FROG SHELL	_Bursa bubo_

CYMATIIDAE

PACIFIC TRITON	_Charonia tritonis_

TONNIDAE

PARTRIDGE TUN	_Tonna perdix_

OLIVIDAE

PURPLE-MOUTHED OLIVE	_Oliva episcopalis_

VASIDAE

PACIFIC TOP VASE	*Vasum turbinellus*

MITRIDAE

EPISCOPAL MITER	*Mitra mitra*
PONTIFICAL MITER	*Mitra stictica*
AUGER-LIKE MITER	*Mitra terebralis*

VENERIDAE

LETTERED VENUS	*Tapes literata*

CONIDAE

LEOPARD CONE	*Conus leopardus*
GENERAL CONE	*Conus generalis*
EBURNEUS CONE	*Conus eburneus*
MARBLE CONE	*Conus marmoreus*
PACIFIC LETTERED CONE	*Conus litteratus*
HEBREW CONE	*Conus ebraeus*
VIRGIN CONE	*Conus virgo*
DISTANT CONE	*Conus distans*
TEXTILE CONE	*Conus textile*
LITHOGRAPH CONE	*Conus litoglyphus*
GEOGRAPHY CONE	*Conus geographus*

TEREBRIDAE

MARLINSPIKE	*Terebra maculata*
MUSCARIA AUGER	*Terebra areolata*
TIGER AUGER	*Terebra felina*
EYED AUGER	*Terebra guttata*
CRENULATA AUGER	*Terebra crenulata*

PECTINIDAE

MANTLE SCALLOP	*Gloripallium pallium*

TRIDACNIDAE

GIANT CLAM	*Tridacna gigas*
FLUTED GIANT CLAM	*Tridacna noae*

LUCINIDAE

PACIFIC TIGER LUCINE	*Codakia tigerina*
PUNCTATA LUCINE	*Codakia punctata*

TELLINIDAE

VIRGATE TELLIN	*Tellina virgata*

CARDIIDAE

HEART COCKLE	*Corculum cardissa*
HALF-HEART COCKLE	*Hemicardium hemicardium*

In addition to the shells listed above, members of the following families (genus and species unknown) are represented in the collection: *Arcidae*, *Pinnidae*, and *Spondylidae*. Also to be found on Namoluk are the cephalopod chambered nautilus (*Nautilus pompilius*), although it is uncommon, and several species of octopi.

ACANTHASTER PLANCI

Samples of gonad tissue from *Acanthaster planci* were taken, along with the soft tissue from *Charonia tritonis*, between 21 and 23 May 1970 for L. R. McCloskey to assist his work as a member of the Westinghouse Pacific Reef Starfish Expedition in 1969. *Acanthaster* has not exploded in numbers on Namoluk as it has elsewhere in the Pacific (e.g., on Truk), and the residue levels of organochlorine pesticides reported for the tissues of specimens from the atoll were very low (McCloskey and Deubert 1972).

INSECTS

Several hundred Namoluk insects with accompanying information on place and time of capture (day or night) form a collection in the

Bernice P. Bishop Museum, Honolulu, Hawaii. Taken during 1970-1971, nearly all of these specimens remain to be identified. Two cockroaches (Periplaneta americana and Pycnoscelus surinamensis) and two flies (Musca domestica and Hemipyrellia sp., probably tagaliana) have been identified by Frank J. Radovsky, Acarologist, Bishop Museum in assistance of the Namoluk toxoplasmosis study since they were of potential significance as mechanical vectors for the parasite.

As a separate enterprise, vertebrate ectoparasites were collected from humans, pigs, cats, fruit bats, both species of rats, chickens, a black noddy, and the large Eugongylus skink for Nixon Wilson at the University of Northern Iowa. Identifications for some of these ectoparasites have now been published (Wilson 1972).

VASCULAR FLORA

Duplicate collections of the vascular plants of Namoluk Atoll were made during June and July 1971, and have been deposited in the National Herbarium, Washington, D. C., and the Bernice P. Bishop Museum, Honolulu, Hawaii. With the exception of certain large well-known plants noted only by sight records (coconut, breadfruit, taro, banana, papaya), these collections are exhaustive. Although mosses, algae and fungi abound in the atoll's moist, humid climate, no attempt was made to gather nonvascular plants.

Girschner claims that in the first decade of this century Namoluk people could name about eighty plants (1912:125), and he provides a list of seventy-five of these names (1913:181-182). A few other plants not included in this list are mentioned elsewhere in the text of his article (1912:140, 141, 157). It is unclear from Girschner's account whether the list of plant names he collected refers specifically to plants growing on Namoluk at that time or whether it is simply a compilation of all plant names known to Namoluk persons, whether or not the plants actually grew on the atoll. Whatever the case, Girschner provides local names for twenty-three plants that are not found on the atoll today. While it is likely that some of this discrepancy is a result of language change, it is equally probable that some plant species have become extinct on Namoluk in the sixty years since Girschner's visit.

In 1971, Namoluk informants had local names for ninety-eight plants growing on the atoll. Fifteen of these plants are known to have been introduced since Girschner's research. These are as follows: Cenchrus echinatus, Panicum maximum, Zoysia matrella, Hedychium coronarium, Mirabilis jalapa, Annona muricata, Caesalpinia pulcherrima, Citrus aurantifolia, Hibiscus (ornamental hybrid), Ceiba pentandra, Cucurbita moschata, Polyscias fruticosa, Plumeria rubra, Coleus scutellariodes, and Capsicum frutescens. Of the twenty-three plants listed by Girschner that no longer occur on Namoluk, the name of only

one was familiar to most informants in 1971: kamwitei 'sweet potato'. The fact that sweet potatoes were introduced to the atoll in the replanting following the 1958 typhoon (Davis 1959b) probably accounts for this recognition. Sweet potatoes have not survived. Ten other plants for which there are no local names are known to have been brought to Namoluk within the past sixty years. The following species fall into this category: Araucaria heterophylla, Eragrostris tenella, Zephyranthes rosea, Moringa oleifera, Intsia bijuga, Pongamia pinnata, Acalypha hispida, Codiaeum variegatum, Barleria cristata, and Cordyline fruticosa.

As a general rule, where Namoluk people have a local name for a plant they have discovered uses for it, and where they have not given a plant a name they have not found ways to use it. Only three of the ninety-eight named plants are not used: Cenchrus echinatus, Paspalum conjugatum, and Paspalum distichum. The former two of these appear to have been mamed because of certain notable characteristics: Cenchrus echinatus is called sätan 'Satan' after its devilish thorns, and Paspalum conjugatum is known as fätilimwän 'male grass' ostensibly because it resembles the male member. Seven of the unnamed plants that occur on the atoll are used, and five of these are relatively recent introductions. None of the uses to which these plants are put is particularly important or unique. Digitaria setigera serves as a mulch in the taro gardens, Eragrostris tenella, Acalypha hispida, and Phyllanthus urinaria contribute material for leis, Moringa oleifera is exploited for firewood, Codiaeum variegatum is planted as a boundary marker, and the wood of Intsia bijuga is used in construction.

Fifty-seven families of vascular plants are found on Namoluk, consisting of 113 identified species and six specimens identifiable only by genus. This compares favorably with collections from similar islands elsewhere in the Carolines: Fosberg (1969) reports 103 species for Satawal, and Fosberg and Evans (1969) record 120 species from Fais.

Nine of the fifty-seven families present are represented by only one species known to have been introduced in the last sixty years. These are: Araucariaceae, Annonaceae, Moringaceae, Liliaceae, Bombacaceae, Cucurfitaceae, Araliaceae, Solonaceae, and Acanthaceae. The Gramineae are the most common on the atoll with thirteen species, followed by the Polypodiaceae with eight species represented.

Seventy-four Namoluk plants are employed in traditional herbal medicine. This is an impressive pharmacopoeia, representing as it does three-fourths of the locally named plants on the atoll. Readers interested in further details on the uses of plants in Trukese herbal medicine -- of which Namoluk herbal medicine is a part -- are referred to Mahony (1970).

At the present time, taro excavations exist only on Namoluk and Töinom Islets, with the Namoluk swamp by far the larger. Amwes Islet formerly had a taro swamp nearly as big as that on Namoluk Islet, but when the Amwes community was abandoned in the late 1930s the swamp was

neglected, and it has become overgrown with a dense stand of Hibiscus tileaceus and Glochidion. Lukan and Umap Islets are too small to have a fresh-water lens, and consequently swamp taro has never grown there.

The atoll's only mangrove forest thrives along the sheltered lagoon shore of Amwes Islet, with both Rhizophora mucronata and Bruguiera gymnorhiza growing in abundance (see plates 3 and 13). Associated with the mangroves are substantial numbers of Thespesia populnea. Mangroves also grow singly or in small clumps on the reef between Amwes and Umap and between Töinom and Lukan Islets (see plate 4).

In the annotated list of vascular plants that appears below, the letter "G" has been added following the local name for all plants mentioned by Girschner (1912, 1913).

Annotated List of the

Vascular Plants of Namoluk Atoll

Eastern Caroline Islands,

Identifications by F. R. Fosberg

POLYPODIACEAE

Asplenium nidus L.

Found growing usually amidst dense brush or on the trunks of trees (especially breadfruit) (see plate 5). Leaves sometimes are used to line pits for preserved breadfruit and to wrap food for cooking; young, unopened leaf stalks are employed in local medicine. Occasionally, small bits of the trunk are cut to plug lashing holes on canoes to retard leakage. Namoluk I. Marshall 46 (US); "lek" (Birds nest fern); G.

Athyrium blumei (Bergsm.) Copel.

Grows commonly on the ground and on fallen logs in partial shade. Leaves are used as mulch for Colocasia esculenta, and the unopened leaf stalk, "trunk," and roots find use in herbal medicine. Namoluk I. Marshall 78 (US); "imwen liles."

Nephrolepis acutifolia (Desv.) Christ

Normally found epiphytic on tree trunks (see plate 6). Leaves serve as a wrapper for breadfruit, and the leaflets are plucked off as a sort of "adding machine" to keep track of breadfruit being harvested in heavily overgrown areas. The young leaf stalk is used in medicinal concoctions. Namoluk I. Marshall 26 (US); "amärä;" G.

Nephrolepis biserrata (Sw.) Schott?

To be found in dense brush and shade on the ground and on fallen logs (see plate 6). Uses are the same as for Nephrolepis acutifolia -- Namoluk people do not differentiate between these two species. Namoluk I. <u>Marshall</u> <u>68</u> (US); "amără;" G.

Polypodium scolopendria Burm. f.

Very common on the ground and growing up the trunks of breadfruit and coconut trees. Leaves are used in leis and to cover food to be baked in an earth oven before dirt is piled on, and the leaves and runners are used medicinally. Namoluk I. <u>Marshall</u> <u>13</u> (US); "chichi."

Pteris tripartita Sw.

Grows in shaded locations near the center of the islets among thick brush. Leaves are used as mulch for Colocasia esculenta, and in herbal medicine. Namoluk I. <u>Marshall</u> <u>17</u> (US); "mwelines."

Thelypteris interrupta (Willd.) Iwats.

Found only in the taro swamps, it is uprooted and used as a mulch for all varieties of taro. Its leaves serve a medicinal function, and were formerly an ingredient in black dye (Girschner 1912:157). Namoluk I. <u>Marshall</u> <u>83</u> (US); "amără en le pwŏl."

Vittaria incurvata Cav.

Specimen was growing on the trunk of a large Barringtonia asiatica along the lagoon shore in heavy shade. Not used by Namoluk people. Tŏinom I. <u>Marshall</u> <u>107</u> (US); no local name.

ARAUCARIACEAE

Araucaria heterophylla (Salisb.) Franco

Only a single specimen exists on the atoll, 4 to 5 meters in height. It was brought to Namoluk from the Truk Agricultural Station on Moen, Truk, and planted next to a house. Not used by Namoluk people. Namoluk I. <u>Marshall</u> <u>61</u> (US); no local name (Norfolk pine).

PANDANACEAE

Pandanus cf. tectorius Park.

At least four distinct named varieties are recognized by Namoluk persons: "fachewel" G. (108); "sillau" G. (113); "pokou" G. (114); and "fachaire" G. (116). In addition, a fifth variety recognized on the atoll (of which there is only one specimen and for which

there is no local name) (115) reportedly was introduced from the Marshall Islands by way of the Truk Agricultural Station during the replanting following the devastation of typhoon Phyllis in 1958. Varieties of pandanus are referred to collectively as "fach." "Fachewel," "sillau," "fachaire," and the unnamed Marshallese variety all grow in relatively open areas along the shore (particularly the lagoon shore); "pokou," by contrast, prefers sheltered areas in the interior of the islets. Leaves of "fachewel," "sillau," "fachaire," and the introduced species from the Marshalls are used for making thatch for roofing canoe houses, cooking houses, and the few remaining traditional thatch sleeping houses; the ripe fruit of all these varieties either is chewed or eaten. The trunk of "fachewel" is used in sleeping house and canoe house construction, and the aerial roots that have not reached the ground (and hence are soft inside) are stripped into long fibrous strands that serve as "thread" to sew pandanus leaves into large panels for thatching. Aerial roots of "pokou" and "fachaire," and occasionally those of "sillau" and the Marshallese variety also are used for this task. Aerial roots of "fachewel" and "fachaire" that have reached the ground and grown tough and hard inside are valued materials for building fish traps. The fragrant blossoms of "fachewel" appear regularly in leis, and leaves of this variety are prized for weaving mats, hats, and handicraft items. Leaves of "pokou" are the preferred material for lining preserved breadfruit pits, and also for weaving baskets for breadfruit seeds. Strips of pandanus aerial root are cut to tie leaf packages of preserved breadfruit before cooking. The "bump" of a newly formed aerial root of "fachewel" may be used to treat boils; roots of all named varieties except "pokou," fruit and bark of "fachewel" and "pokou," and the leaves and the stem of the fruit stalk of "pokou" all are used in medicines. Namoluk I. Marshall 113, 114, 115, 116 (US); Toinom I. Marshall 108 (US).

Pandanus sp. (very young) ?

Although the botanist could not identify this species on the basis of the material collected, the anthropologist is quite certain that it is not simply a very young specimen of one of the other varieties. In asking informants for names of different plants, "lifach" was commonly volunteered. Significantly, Girschner also collected the name for this plant (1913:182). Furthermore, Namoluk persons readily identify the plant and know where a particularly large stand of it grows near a well at the edge of the main taro swamp. Although no fruit of this species were observed, Namoluk persons uniformly emphasized that they are red in color in contrast to the orange or yellow color of the fruit of (108), (113), (114), (115), and (116). Aerial roots of this plant are used in construction of fish traps and its leaves are employed in medicine. Namoluk I. Marshall 90 (US); "lifach;" G.

GRAMINEAE

Cenchrus echinatus L.

Found in open sunny areas and distinguished by its small thorny burrs from which derives its Namoluk name: "sätan" from the English 'Satan', 'devil'. Namoluk people make no use of this plant which reportedly was introduced accidentally from Moen, Truk. Namoluk I. Marshall 29 (US); "sätan."

Centotheca lappacea (L.) Desv.

Forms a ground cover interspersed with ferns under coconut palms on the seaward side of the islet. No local use. Namoluk I. Marshall 74 (US); no local name.

Chrysopogon aciculatus (Retz.) Trin.

Prefers open areas especially around homes and public buildings. Not used by Namoluk people. Namoluk I. Marshall 20 (US); no local name.

Digitaria setigera Roth

Thrives along beach strand above the high water mark under coconut palms; this grass is gathered, dried, and used as a mulch in the taro gardens. Namoluk I. Marshall 35 (US); no local name.

Eleusine indica (L.) Gaertn.

Sunny, sandy cleared areas around homes provide the major habitat for "fätilimwech" whose name means literally 'hard to uproot grass'. Clumps of "fätilimwech" formerly were placed under newly built canoes just prior to launching in order to prevent drifting (the "uprooting" of the anchored canoe). This grass often is cooked along with taro or breadfruit to prevent scorching of the food although it is not eaten itself. When dried, "fätilimwech" finds use as a mulch for taro. The entire plant is pounded, mixed with the water of a green coconut, and drunk as an antidote for bloody stools on the assumption that its clinging properties will prevent further loss of blood. Namoluk I. Marshall 1 (US); "fätilimwech."

Eragrostis tenella (L.) Beauv.

The specimen collected was found growing in a shaded path among moss. Ostensibly brought to the atoll from Truk during the Japanese period, the seed stalks of this grass are sometimes used in leis. Namoluk I. Marshall 77 (US); no local name.

Lepturus repens var. subulata Fosb.

Found growing from a sand dune at the end of a long spit (see plate 7). This plant has no local uses. Amwes I. Marshall 124 (US); no local name.

Lepturus repens R.Br.? (sterile)

Located in an absolutely clear sunny field among other low grasses. The stems are used to manufacture small fish traps for several kinds of reef fish that frequent shallow areas. The leaf tip is used to stroke the throat while a chant is uttered in an effort to dislodge fish bones that inadvertently have been swallowed, and the seed and flower stalk is a medicinal ingredient. Namoluk I. Marshall 70 (US); "fätilen uu nom."

Panicum maximum Jacq.?

Reportedly brought to Namoluk from Etal Atoll in 1966 or 1967, only one large clump of this striking grass is to be found planted next to a person's house. The leaves are used in leis and in local perfume because of their pleasing aroma. Namoluk I. Marshall 27 (US); "paki ngeni" (Pampas grass).

Paspalum conjugatum Berg.

Grows in open sunny places among other grasses; Namoluk people have found no use for this plant. Namoluk I. Marshall 21 (US), 72 (US); "fätilimwän."

Paspalum distichum L.? (sterile)

Observed only in sunny clearings or along open paths. No local uses. Namoluk I. Marshall 65 (US); "unaf."

Saccharum officinarum L.

Cultivated in the taro swamp. Today the stems are chewed and sucked as a pleasant treat, although they used to be cooked and pounded to extract sugar when none was available from commercial sources. Juice from the stems is used medicinally. Namoluk I. Marshall 88 (US); "uou" (Sugar cane); G.

Zoysia matrella (L.) Merr.

Planted in open sandy areas around people's homes because it forms a comfortable mat on which to sit and because it chokes out taller grasses. Reportedly brought to Namoluk from Oneop Islet, Lukunor Atoll in 1959. Namoluk I. Marshall 2 (US); "sipa" (Japanese name).

CYPERACEAE

Fimbristylis cymosa R.Br.

Prefers damp locations and sandy soil in areas that are not heavily overgrown with underbrush. The plant is used medicinally, and in olden times was used to make fishing lures (Girschner 1912: 153). Namoluk I. Marshall 3 (US); "puker uon fanu."

Rhynchospora corymbosa (L.) Britt.

To be found only in the taro swamps, the leaves, seeds and main root of this reed are used medicinally. Namoluk I. Marshall 84 (US); "kushukush."

Cyperaceae

Specimen collected was found growing in the main taro swamp; identification by informants was only tentative. The leaves and stems are a medicinal ingredient. Namoluk I. Marshall 102 (US); "puker en le pwöl?"

PALMAE

Cocos nucifera

Namoluk persons recognize numerous named varieties of coconut, many of which have been introduced to upgrade local copra production; no effort was made to collect botanical specimens of these different varieties (for a partial list see Girschner 1912: 140). Coconut is probably the most widely used plant on the atoll. The fruit is eaten at several stages (e.g., the soft gelatinous "meat" in green nuts, the hard crunchy copra, and the spongy mass filling a sprouted nut), the fluid of green nuts provides a refreshing beverage and is also an essential ingredient in many culinary and medicinal recipes, and "coconut cream" is wrung from grated copra as a sauce for many prized dishes. In addition, coconut meat serves as a major feed for pigs and domestic fowl, and when dried as copra provides the atoll's only cash crop. Coconut roots are used in manufacture of fish traps and woven bags, the wood provides lumber, posts, bowls, and formerly, weapons and fishing spears, and many parts of the palm are used for firewood. The main stem of the frond serves as a base to which pandanus leaves are attached in making thatch panels, and whole fronds are placed loosely on the roofs of canoe houses and thrown down as a ground cover in traditional style dwellings. Fronds also may be woven into very versatile baskets almost at a moment's notice, and are used to shield canoes from the rays of the sun and in fish drives. Leaves from unopened fronds afford material for handicrafts, traditional body decoration, holiday decorations and ornaments, toys, and model canoes. Several fronds woven together serve as torches to light the night when seeking

flying fish, and coconut leaves tied around tree trunks mark off land that is taboo (pwau) from exploitation. Numerous food containers and baskets are woven from coconut leaves. The midribs of single leaves act as toothpicks and make good brooms when bunched together and tied to a handle, and they are extremely important in knot divining (cf. Girschner 1912:199). Coconut sap is tapped for both sweet and fermented toddy, and heart of palm occasionally is eaten. Leaf midribs are used as sticks for roasting breadfruit nuts and small fish over a fire, and the "coconut boat" is used both as firewood and as a handy splint for broken limbs. The stems that attach to nuts are frayed and make satisfactory paint brushes, and the husk of the ripe nut is soaked and dried and used to make sennit cord and rope. Leaves may be turned into hats and fans, and in olden days coconut shell was formed into fishhooks, earrings and a host of other decorative and utilitarian items. Water from green coconuts forms a basic ingredient in a great many medicinal mixtures, and nearly every part of the tree is employed in different medicinal remedies. There are many other uses for coconut products not mentioned here, but it should be apparent that every part of the plant is used in some way. Marshall (sight record) "Nu" (Coconut); G.

ARACEAE

Alocasia macrorrhiza (L.) Schott

This plant largely grows wild on the atoll and is viewed as a famine food. Several parts of the plant are employed in traditional herbal medicine. A few people plant "kä" near their homes to make use of the large leaves as containers in food preparation, and children often break off a leaf as an impromptu umbrella. The flowers sometimes find their way into leis. Marshall (sight record) "Kä"; G.

Colocasia esculenta (L.) Schott

The corm of this plant, which is ready to eat in about six months from planting, forms one of the three staple crops on the atoll along with Cyrtosperma taro and breadfruit. The flowers are used in leis, and the leaves are used in medicine. Numerous subvarieties are named by informants (cf. Girschner 1912:140; Mahony 1960:96). Marshall (sight record) "Oat" (Taro); G.

Cyrtosperma chamissonis (Schott) Merr.

Planted much more widely on Namoluk than Colocasia esculenta, Cyrtosperma is reputed to be more tolerant of salt spray and has the advantage that it remains edible when left in the ground for long periods of time. The corm is a mainstay of the Namoluk diet, leaves, stems and the corm are used in medicine, leaves are used to wrap food, and other parts of the plant are used as fertilizer in the taro swamps. Informants recognize many

different sub-varieties (cf. Mahony 1960:97-98). Marshall (sight record) "Pula" (Taro); G.

LILIACEAE

Cordyline fruticosa (L.) Chevalier

This is what is called ti plant in Hawaii -- specifically, the kind with variegated green and purple leaves. This plant, brought to the atoll in 1967 from Moen, Truk by a Peace Corps Volunteer resident on Namoluk at that time, is planted near houses and lining paths in the village area. Namoluk I. Marshall 25 (US); no local name; ti in Hawaiian.

AMARYLLIDACEAE

Crinum asiaticum L.

Often planted near houses for their attractive flowers, these lilies also grow wild in coconut groves near the lagoon beach. Their flowers are used in leis, the leaves are used to wrap food before cooking (especially certain kinds of fish), and the "skin" of the main trunk is sometimes incorporated into trolling lures for tuna and other game fish. Leaf fibers used to serve as wound dressings before gauze and cloth became available, and leaves, fruits, flowers and roots form ingredients in various medicinal recipes. Namoluk I. Marshall 36 (US), 105 (US); "püllai" "kiop" (Crinum lily); G.

Hymenocallis littoralis (Jacq.) Salisb.

Planted near houses and lining paths in generally sunny areas; some have gone wild in the vicinity of the village. Uses for this plant are the same as for Crinum asiaticum; Namoluk persons do not distinguish between the two terminologically. Namoluk I. Marshall 19 (US); "püllai" "kiop" (Spider lily); G.

Zephyranthes rosea (Spr.) Lindl.

Found only around people's houses where it is planted for its beautiful flowers; the flowers are used in leis and to decorate church altars. Namoluk I. Marshall 49 (US); "pilip" (Lily).

DIOSCOREACEAE

Dioscorea alata L.?

Usually found growing along the ground and climbing on underbrush in densely wooded areas near the middle of the islet. The aerial tubers are recognized as a potential famine food, but are not normally eaten. Namoluk I. Marshall 62 (US); "ep."

Dioscorea bulbifera L.

Wanders along the ground, over shrubbery, and up trees everywhere except near the beach. The aerial tubers, reported to be very bitter, are edible if cooked several times and traditionally were served as a famine food. Namoluk I. Marshall 63 (US); "pereka."

TACCACEAE

Tacca leontopetaloides (L.) O.Ktze.

Formerly partially cultivated, this plant now grows wild in relatively open coconut groves near the beach. The bulbous, fleshy tubers once were collected and pounded into an edible flour, but with the advent of commercial supplies of flour this has ceased. The fruits are used in leis, the leaves are essential in the treatment of persons thought to have been bitten by a sea ghost and the stem has other medicinal uses. Namoluk I. Marshall 39 (US); "mökumök" (Arrowroot); G.

ZINGIBERACEAE

Curcuma sp.

Several varieties were collected, however, all were unfortunately sterile which prohibited more positive identification. One kind (60), found in thick, black muck in one of the smaller taro excavations, is said by informants to have bright red flowers although these were not observed. It does not have a use or a local name on Namoluk. A second form (94) was collected in the main taro swamp and is called "afan." The fragrant leaves of "afan" are used in leis and love magic and to spice coconut cream. The bulb root also plays a role in love magic, and along with the leaves is employed in many herbal remedies. A final type (106) also was gathered in the taro swamp and its flowers and fruits are incorporated into leis; this kind is said by informants to have been introduced from Truk. Namoluk I. Marshall 60, 94, 106 (US); "afan" (94) G., no local name (60), (106).

Hedychium coronarium

Partially cultivated in the taro swamps, this plant is not common on the atoll but is highly prized for its deliciously fragrant blossoms which are used in leis. Namoluk I. Marshall 93 (US); "sinser" (White ginger).

MUSACEAE

Musa sapientum L.

As with coconuts, a great many named varieties of banana grow on the atoll. Some are prized for eating raw, others for cooking,

and a few as food for domestic animals. Bananas are semi-cultivated both in the village area and in the bush; people know the locations of their banana plants, and check them periodically to see if any are ripe. Banana leaves are used in earth ovens, offer fiber for leis (and, formerly, for wrap-around clothing woven on hand looms), and serve as ready-made plates, table mats, food wrappers and umbrellas. Various parts of the banana plant are employed in traditional medicine. Marshall (sight record). "Uuch" (Banana); G.

PIPERACEAE

Piper fragile Benth.

Namoluk people call this common vine "atoopwei." It is found in heavily shaded areas trailing along the ground and off shrubbery, and occasionally twining around large trees (see plate 6). "Atoopwei" has a number of medicinal uses. Namoluk I. Marshall 15 (US); "atoopwei;" G.

Piper ponapense C.D.C.

The specimen is juvenile, but the information given below was sufficient for the botanist to reliably distinguish it from P. fragile. This vine grows in thickly wooded areas away from the beach. Namoluk persons call it "anek," and it is an important constituent in leis and love magic. In addition, stems and leaves of "anek" were combined with leaves of Polypodium scolopendria to make a crown placed on the head of the atoll chief on his investiture when the traditional political system was still intact. Namoluk I. Marshall 89 (US); "anek;" G.

URTICACEAE

Pipturus argenteus (Forst.f.) Wedd.

The specimen was growing in a rocky area of dense vegetation about 45 meters from the beach. Trunk wood and saplings are used in house construction, the bark formerly was used to manufacture a very strong fishline, and the leaves are fed to pigs. When mixed with grated copra, the fruit are applied as a treatment for skin rashes, and the bark also finds use in medicines. Namoluk I. Marshall 51 (US); "aroma."

Laportea ruderalis (Forst.f.) Chew

This plant, whose local name means 'ants' coconut palm', grows in cleared coconut groves near the beach. The entire plant is used in certain medicines. Namoluk I. Marshall 38 (US); "an ukech nu."

MORACEAE

Artocarpus altilis (Park.) Fosb.

Breadfruit in its many named sub-varieties, forms the preferred staple in the Namoluk diet (cf. Girschner 1912;139 for a list of named varieties on Namoluk in 1910). In addition to eating both the fruit and the seeds of the seeded types, Namoluk people use breadfruit leaves as plates and wrappers for food to be cooked. Large trees provide the major local source of lumber for heavy construction, for canoe hulls, and for many important cooking utensils. Dead branches frequently are gathered for firewood, and the sticky sap serves as a caulk for canoes. Finally, nearly every part of the plant is employed in herbal medicine. Marshall (sight record). "Mei" (Breadfruit tree); G.

Ficus tinctoria Forst.

A common understory component in breadfruit forests. The fruits are eaten as a famine food and woven into leis, and saplings are used for outrigger attachments and other canoe parts and in house construction. Bark is formed into lures for pelagic fish, Y-shaped branches are cut as rims for two types of fishing net, and the leaf sheath and roots are used medicinally. Namoluk I. <u>Marshall</u> <u>10</u> (US); "auwen;" G.

Ficus prolixa var. carolinensis (Warb.) Fosb.

There is only one of these majestic trees in the whole atoll, located in a dense forest of Premna obtusifolia and Glochidion near the ocean side of Amwes Islet. The trunk of this tree is almost 3 meters in diameter and the tree stands an estimated 25 meters high. There are no major uses for this tree, although its aerial root bark is an ingredient in herbal medicine. Amwes I. <u>Marshall</u> <u>119</u> (US); "kiliau" (Banyan tree); G.

POLYGONACEAE

Polygonum minus var. procerum (Danser) Steward

Grows only in taro bogs. Uprooted and used as a mulch for Cyrtosperma chamissonis. Young leaves are used in medicine for women. Namoluk I. <u>Marshall</u> <u>79</u> (US); "opulöulöu;""G.

AMARANTHACEAE

Achyranthes aspera L.

Rocky soil in relatively clear coconut groves is where this plant is to be found. It has several medicinal uses. Namoluk I. <u>Marshall</u> <u>76</u> (US); "uökö."

Alternanthera sessilis (L.) R.Br. ex R.&S.

Occurs only in the taro excavations. No local uses. Namoluk I. Marshall 95 (US); no local name.

NYCTAGINACEAE

Mirabilis jalapa L.

Planted next to people's houses where its flowers may be readily picked for leis. Its local names mean "turtles' perfume" and "three-o-clock," the latter in reference to its blossoms which regularly open about 3:00 P.M. The flowers are used medicinally. Namoluk I. Marshall 43 (US); "apetin woun" "kuhok elu."

Pisonia grandis R.Br.

These large trees are found just above the high water mark, usually along the lagoon shore beach. Saplings are used for fences and dead branches make good firewood; Namoluk people say the wood is too weak for other uses. The leaves are fed to pigs, are used as a mulch for Colocasia esculenta, and are employed medicinally. Namoluk I. Marshall 48 (US); "mwŭk;" G.

PORTULACACEAE

Portulaca australis Endl.

Grows in comparatively open areas, e.g., along paths in partial shade. The leaf stem is a medicinal ingredient. Namoluk I. Marshall 16 (US); "puson."

ANNONACEAE

Annona muricata L.

Only a single specimen exists on the atoll which was brought from Truk and planted for its edible fruit. Namoluk I. Marshall 22 (US); "sasaf" (Soursop).

LAURACEAE

Cassytha filiformis L.

Found in beach strand vegetation in a matted, tangled mass at the high water mark, this plant's stem is used medicinally by Namoluk people. Namoluk I. Marshall 75 (US); "uŏlau."

HERNANDIACEAE

Hernandia sonora L.

Found growing nearly everywhere, the wood of this tree is used as firewood, and its leaves and seeds are incorporated into medical concoctions. Girschner mentions its leaves as an ingredient in black dye (1912:157). Namoluk I. Marshall 18 (US); "akurang;" G.

CAPPARIDACEAE

Crateva speciosa Volk.

Grows all over the interior portions of the islets amidst heavy brush. The pungent fruit is eaten but not cultivated, and it is also sliced thin and woven into leis. The trunk often is cut and used as a disposable coconut husking stake, and the leaves serve as mulch for Colocasia esculenta and as a medicinal ingredient. Namoluk I. Marshall 50 (US); "afuch."

MORINGACEAE

Moringa oleifera Lam.

One large tree growing next to a house is the only one known for the entire atoll; this specimen is remembered by informants to have been introduced by the Truk Agricultural Department in the replanting after typhoon Phyllis in 1958. Some informants heard that the species had been brought to Truk from the Philippines and that its leaves are edible in soup, although no one on the atoll has tried them. Its only local use is as firewood. Namoluk I. Marshall 30 (US); no local name.

LEGUMINOSAE

Caesalpinia pulcherrima (L.) Sw.

All of the specimens on the atoll have been planted next to people's houses to facilitate gathering the blossoms for leis; both the variety with bright yellow and that with striking red-orange flowers occur on Namoluk. Occasionally, large branches are cut into coconut husking stakes. Although "simota" grew on Namoluk pre-typhoon Phyllis, they were all destroyed in the storm and were reintroduced from Truk in 1958 or 1959. Namoluk I. Marshall 7 (US); 86 (US); "simota" (7), (86) (Flame tree).

Canavalia cathartica Thou.

Usually grows near the beach in coconut plantations where it frequently climbs on trees and shrubs. The hard seeds are strung for leis, and the leaves serve in local medicine. Namoluk I. Marshall 41 (US); "anikat;" G.

Derris elliptica (Roxb.) Benth.

A vine that is found only in deeply shaded, overgrown areas near the center of the islets. Formerly, its roots were pounded and used to poison fish in tide pools so that they could be easily gathered (Girschner 1912:153). Its stems have medicinal properties. Namoluk I. Marshall 45 (US); "uup."

Derris trifoliata Lour.?

This low shrub was located in a cleared shady area under coconut palms with almost no underbrush. It has no local uses. Amwes I. Marshall 121 (US); no local name.

Intsia bijuga (Colebr.) O.Ktze.

Informants say this tree has not grown on Namoluk for very many years. They speculate that its seeds may have drifted to Namoluk and taken root; one informant resident in Palau for several years asserts that it grows there. It is found in a thick forest of Pemphis acidula and Cordia subcordata with no underbrush. The wood is said to be very strong, and Namoluk people use it in building construction and at stress points for ropes on sailing canoes. Töinom I. Marshall 111 (US); no local name.

Pongamia pinnata (L.) Merr.?

A single example of this tree is all that was observed. It was growing just above the high water mark on a heavily eroded bank along the lagoon shore. Not used locally. Amwes I. Marshall 122 (US); no local name.

Vigna marina (Burm.) Merr.

Found along beach strand under coconut palms and extending out to the high water mark. Juice expressed from leaves of this vine is used to treat chickens suffering from "eye sickness" by squeezing it into their eyes, mouths and anuses. Juice from the pounded stems forms part of a medicinal concoction drunk by women for stomach pain and slight cough. Its leaves were once an ingredient in black dye (Girschner 1912:157). Namoluk I. Marshall 34 (US); "oolu;" G.

RUTACEAE

Citrus aurantifolia (Christm.) Swingle

These small trees are planted near houses and in the interior, and are prized especially for their fruit. The limes are eaten, and their juice is squeezed over raw fish. Leaves also figure in cooking as a flavoring for soup, occasionally are boiled as a substitute for coffee and are used in herbal medicine. Supple

saplings are bent into frames for fish nets, and the wood is fashioned into adze handles and outrigger attachments for canoes. Namoluk I. Marshall 28 (US); "laimes" (Lime).

Citrus aurantium L.

These trees are both planted and grow wild in well-watered, partially shaded areas away from the beach. The extremely sour oranges are eaten or squeezed for their juice to which sugar is added. Fragrant roots are used in leis, the tough wood sometimes is used for coconut husking stakes, and long, straight branches formerly were very important as staves in stick dancing and warfare (these staves, like the plant, were called "kurukur"). The bark is used in medicines. Girschner reports that the thorns were used as tatoo needles (1912:131), although later he makes the strange comment "There are no oranges." (1912:141) (Translation by Diana Maughan). Namoluk I. Marshall 64 (US); "kurukur" (Sour orange tree); G.

SIMAROUBACEAE

Soulamea amara Lam.

To be found in dense brush everywhere, but particularly near the beach. Long saplings are used as poles for poling canoes along the reef, and in building construction; small saplings are used to make the outrigger platforms on canoes. Medicines are made using the bark as an ingredient. Namoluk I. Marshall 53 (US); "märas;" G.

MELIACEAE

Aglaia ponapensis Kanehira?

Only a single leaf was collected, so the identification is tentative indeed. This species has not been recorded previously outside Ponape and the genus is not known hitherto from any coral atoll. Only a single specimen of this tree grows in the whole atoll, just behind the mangrove swamp right at the high water mark on the lagoon shore of Amwes Islet. The tree was about 11 meters high. This plant is not used locally. Amwes I. Marshall 118 (US); no local name.

EUPHORBIACEAE

Acalypha hispida Burm.f.

Planted next to people's houses in the bright sunshine, this plant was brought to Namoluk from the Truk Agricultural Station on Moen. Its red, fuzzy, streamer-like flowers are used in leis. Namoluk I. Marshall 59 (US); no local name.

Codiaeum variegatum (L.) Bl.

This colorful plant often grows adjacent to houses, and its major use is to mark boundaries between pieces of land and to delineate graves. Namoluk I. Marshall 14 (US); no local name (Croton).

Euphorbia chamissonis (Kl. & Gke.) Boiss.

Found growing only on the ocean side of a long sandspit among grasses and vines above the high water mark (see plate 7). Used in local medicine. Amwes I. Marshall 123 (US); "pisinom;" G.

Glochidion?

Grows in thickly wooded, deeply shaded, moist areas near the center of the islets. Although the wood is not very strong, it is sometimes used in erecting temporary shelters away from the village area. The unopened leaves have a medicinal use. Namoluk I. Marshall 58 (US); "nge;" G.

Phyllanthus amarus Sch. & Thell.?

The specimen collected was located in an open space in dappled shade. Not used locally. Namoluk I. Marshall 31 (US); no local name.

Phyllanthus urinaria L.

Occurs only in the taro swamps; its small red berries are infrequently used in leis. Namoluk I. Marshall 85 (US); no local name.

SAPINDACEAE

Allophylus timorensis Bl.

A small tree usually found mixed with other brush along the shore. The wood is used for lean-to shelters and as fuel; the leaves are reputed to reduce swelling when crushed and applied to painful swollen bruises. Namoluk I. Marshall 73 (US); "nguner."

TILIACEAE

Triumfetta procumbens Forst.f.

Prefers the relatively cleared ground beneath coconut palms near the shore. Juice from the leaves is squeezed on goggles to prevent fogging up when spear fishing. The leaves also are used in leis and in medicine, and the pounded fruits are mixed with water from a drinking coconut and gargled to relieve a painfully sore throat. The local name for this plant is the same as that for Acanthaster planci, the Crown-of-thorns starfish (perhaps because of its spiny fruits?). Namoluk I. Marshall 40 (US); "ara."

MALVACEAE

Hibiscus tiliaceus L.

On Namoluk, this useful plant only grows in or very near the taro bogs at the middle of the three largest islets. The wood is used in house construction, for the outrigger struts on paddling canoes, as poles for poling canoes on the reef, for the long poles employed in picking breadfruit, in the manufacture of model canoes, and formerly in making men's dance ornaments (Girschner 1912:137). The young leaves, bark, and unopened flowers find their way into medicines, especially those for women. Formerly, bark fibers from this plant were woven into clothing on hand looms, and these fibers also were made into fish nets, slings and twine (Girschner 1912:131, 157). According to Girschner (1912: 167), hisbicus bark also was used to tie the umbilicus of newborn infants. Namoluk I. Marshall 87 (US); "kilifö;" G.

Hibiscus (ornamental hybrid)

These attractive bushes are planted around houses. The only variety found on Namoluk in 1969 boasted a bright pink single blossom with a maroon and white center. Informants emphasized that varieties with other colors of blooms had grown on the atoll in the past, and Marshall introduced a dark red type with a deep maroon center from Moen, Truk in December 1970. This latter type was growing well and had bloomed by July 1971. The flowers are used in leis and as decoration for festive occasions (e.g., on the church altars). Namoluk I. Marshall 47 (US); "rous."

Thespesia populnea (L.) Sol. ex Correa

This tree grows right at the high water mark along the lagoon shore of Töinom and Amwes Islets. Saplings are used for fishing poles and formerly served as fishing spears; the wood is carved into canoe paddles, and the bark is used in herbal medicine. Töinom I. Marshall 109 (US); "pönö;" G.

BOMBACACEAE

Ceiba pentandra (L.) Gaertn.

Grows only in the interior of the main islet of Namoluk where there is plenty of ground water. The cotton-like mass surrounding the seeds enclosed in a heavy pod is used for stuffing pillows. Namoluk I. Marshall 24 (US); "poupou" (Cotton tree).

GUTTIFERAE

Calophyllum inophyllum L.

These gnarly, hardy trees stand right above the high water mark on the lagoon shore, and many reach a height of 15 to 20 meters.

Girschner (1912:136) mentions that, "Fruits of Calophyllum inophyllum are cut crosswise and used for pearls and discs" (translation by Diana Maughan). The dense, durable wood has many uses on Namoluk, e.g., house posts for canoe houses and dwellings, carved bowls (wood from the thick roots also is made into bowls with strikingly beautiful grain), goggles for spearfishing, canoe paddles, outrigger struts, and several other specifically named canoe parts. Formerly, soot from "rakich" wood was rubbed into tatoos (Girschner 1912:131-132). The flowers are used in leis and to scent homemade perfume, and the leaves frequently are transformed into effective toy sailing canoes for children. Both leaves and bark are employed in medicines. Namoluk I. Marshall 98 (US); "rakich;" G.

Mammea odorata (Raf.) Kost.

Not especially common on Namoluk; the specimen collected was growing among dense brush in a coconut grove. The wood is used for house posts and other construction, and for making axe handles. Both the flowers and fruits may be used in leis, and the leaves are employed in treatments administered by traditional massage masters. The bark and the skin of the fruit also play a role in local medicine. Namoluk I. Marshall 97 (US); "lifaus;" G.

CARICACEAE

Carica papaya L.

Although no effort was made to collect specimens, several distinct varieties of papaya exist on Namoluk. Most common is the kind with small pear-shaped fruit; Marshall introduced a variety from Nama Island with watermelon-sized fruit that was bearing by July 1971. Papaya plants are cultivated, particularly around homesites, although a number are growing wild in the bush. The fruit is eaten, the flowers are used in leis, the leaves are scattered around Colocasia esculenta as mulch, and the hollow leaf stem sometimes serves as a ready made straw. Marshall (sight record). "Momiap" (Papaya); G.

CUCURBITACEAE

Cucurbita moschata Duch. ?

"Pwönkin" is the Namoluk rendition of the English word for pumpkin, although this is not the familiar orange pumpkin popular at Halloween. The plant appears to grow in any sunny open spot near the beach, and it is always cultivated. The fruit and the young leaves are eaten (the latter in soup). Namoluk I. Marshall 37 (US); "pwönkin" (Squash).

LYTHRACEAE

Pemphis acidula Forst.

An extremely thick forest of this small tree covers the north-eastern end of Töinom Islet, and scattered clumps grow elsewhere in the atoll in sandy areas along the shore. The lack of any underbrush in the "chekis" forest is especially striking (see plate 8). This tree provides the strongest wood on the atoll -- the heartwood chipped the blade of a machete being used to cut it! "Chekis" wood is used to make thatching needles (cf. Girschner 1912:147), and the wood is the preferred and common material for coconut husking stakes and for stakes to which canoes are tied in shallow water areas. It is also used in building construction and formerly was made into weapons. The bark has medicinal functions. Töinom I. Marshall 110 (US); "chekis;" G.

RHIZOPHORACEAE

Bruguiera gymnorhiza (L.) Lam.

One of two species of mangrove found on the atoll, this species is restricted to the large mangrove swamp located on the lagoon shore of Amwes Islet (see plate 3). It lacks the spider-like aerial roots of its companion species. In the old days the bark was pounded, mixed with charcoal and breadfruit tree sap, and used as a black paint for canoes. Today its wood is exploited for poles for poling canoes along the reef and occasionally for building material. Both the bark and the bright red flowers have medicinal uses. Amwes I. Marshall 120 (US); "eöng" (Mangrove); G.

Rhizophora mucronata Lam.

Far more plentiful than Bruguiera gymnorhiza, this species of mangrove is dominant in the large mangrove swamp on Amwes Islet and is the type that may be found growing in isolated clusters on the open reef between Amwes and Umap Islets (see plate 4) and between Töinom and Lukan Islets. Large branches and aerial roots are used to make multi-pronged fishing spears, men's traditional combs, and fish traps. Occasionally, the trunk is cut to serve as a stake for mooring canoes or for husking coconuts. The bark and leaves are used medicinally. Amwes I. Marshall 117 (US); "chia" Mangrove); G.

LECYTHIDACEAE

Barringtonia asiatica (L.) Kurz

One of the most common trees on the atoll, "kul" grow along the ocean and lagoon shores of all five islets. Often much of their root structure is exposed from erosion but this does not kill the

tree. Namoluk people use the wood for fuel, and the leaves to wrap food. The seeds are grated and introduced into tide pools at low tide to poison small fish. Fish so poisoned are perfectly safe for human consumption. Seeds, flowers and leaves all serve in local medicines. Namoluk I. Marshall 101 (US); "kul;" G.

Barringtonia racemosa (L.) Bl.

Found growing in thick black mud in a small taro excavation near the middle of Namoluk Islet in heavy shade; uncommon. The bark is used medicinally. Namoluk I. Marshall 125 (US); "asol."

MYRTACEAE

Eugenia sp.

These tall (10 to 15 meters) trees stand along the edge of the taro swamps and produce a fleshy, apple-like fruit that is red when ripe and much sought after when it comes into season. Large branches are cut into struts leading to the outrigger on sailing canoes, and the trunk sometimes serves as house posts in building construction. Leaves and bark are constituents of herbal medicines. Namoluk I. Marshall 71 (US); "feniap" (Mountain-apple tree).

COMBRETACEAE

Terminalia catappa L.

These small trees (3 to 4 meters) are found in dense brush near the middle of the islets. The edible seeds sometimes are gathered as a snack, the trunk may be used for house posts when the tree is large, and the larger branches are used in house construction. Namoluk I. Marshall 67 (US); "sif."

Terminalia samoensis Rech.

All specimens observed were growing right at the high tide mark. The red skin and kernel of the nut are eaten irregularly, and the wood has many uses, e.g., for wooden bowls, in building construction, and for canoe paddles. Namoluk I. Marshall 54 (US); "kin;" G.

ONAGRACEAE

Ludwigia octovalvis (Jacq.) Raven

This plant grows in the taro bogs and the whole plant is used medicinally. Namoluk I. Marshall 80 (US); "aieŏ;" G.

ARALIACEAE

Polyscias fruticosa (L.) Forst

Purposefully planted as a hedge lining paths, graves, and land boundaries all over the islets. Clothes often are draped over these hedges to dry in the sun. The plant reportedly was brought to the atoll from Dublon, Truk by an Okinawan man who married and resided on Namoluk during the 1920s and 1930s. Namoluk I. Marshall 44 (US); "sikamor."

UMBELLIFERAE

Centella asiatica (L.) Urb.

Grows as a ground cover in damp shady places. When burned on a fire, the leaves are used to treat a skin ailment also called "mwoi" on the underside of the foot. Namoluk I. Marshall 32 (US); "mwoi."

GENTIANACEAE

Fagraea berteriana var.

This tree reaches a height of at least 10 meters, and the specimen collected was growing as understory in a mixed coconut-breadfruit forest near the seaward side of the islet. The flowers are prized for leis (the plant's local name means literally 'to annoint with a fragrance'), and the yellowed leaves and the flowers are thought to have medicinal properties. Namoluk I. Marshall 100 (US); "apet."

APOCYNACEAE

Neiosperma oppositifolia (Lam.) Fosb. & Sachet

The trees observed were clustered along a wave-eroded bank on the seaward side of the islet in a very rocky area. Their roots were washed by waves at high tide and they were helping hold the land against the destructive action of the sea. Informants said the flat seed kernels may be eaten, though they are not normally consumed on Namoluk. The wood serves in building construction, as poles for poling canoes, and as material for canoe paddles. The leaves are used in local medicine. Namoluk I. Marshall 99 (US); "umwa;" G.

Plumeria rubra L.

Nearly all the plumeria on the atoll are planted in clearings adjacent to dwellings; the plant is reputed to have been brought to Namoluk from Etal Atoll during the Japanese period. Flowers adorn leis and scent local perfume (made with a coconut oil base), the

sticky white sap is used as glue, and the large stems sometimes are carved into goggle frames for spearfishing. Namoluk I. Marshall 11 (US); "pumeria."

CONVOLVULACEAE

Ipomoea littoralis Bl.

This vine occurs only in the taro swamp where it clambers over other vegetation. Its morning glory like flowers occasionally find their way into leis, and the leaves and stems -- when mixed with unfermented coconut toddy and baked in an earth oven -- provide a famine food. Flowers, stems and leaves all are used medicinally. Namoluk I. Marshall 81 (US); "rokurok," G.; "imwen uut."

Operculina turpethum (L.) Manso

The thick white sap of this vine that grows only in the taro bogs is said to sting if it comes into contact with eyes, scratches and cuts. When nothing better is at hand, it sometimes is used as a temporary rope, and the stem and unopened leaves mixed with other plants are used medicinally. Namoluk I. Marshall 92 (US); "afaamach;" G.

BORAGINACEAE

Cordia subcordata Lam.

These trees, which may reach a height of 8 or 9 meters, usually grow in thick stands; the specimen collected was taken from a mixed forest of Cordia subcordata and Pemphis acidula near the ocean side of Tŏinom Islet (see plate 8). The wood is carved into canoe paddles and prows, poles for poling canoes, and also provides a general building material. The flowers are sought for leis, and the bark and leaves have medicinal uses. Tŏinom I. Marshall 112 (US); "anau," G., "aleu;" G.

Tournefortia argentea L.

Found only near the beach in sandy soil, these useful trees easily grow to 10 meters in height. The wood is preferred for specific outrigger canoe parts, for goggles, for carved masks, for firewood, and sometimes for house posts. When leaves of Triumfetta procumbens are unavailable, juice squeezed from "amŏloset" leaves is used to prevent goggles from fogging up under water. Young, unopened leaves are used in treatment of persons afflicted by sea ghosts, and the immature flower stalk is employed in love magic. Namoluk I. Marshall 42 (US); "amŏloset;" G.

VERBENACEAE

Premna obtusifolia R.Br.

This plant seems to grow almost everywhere on the islets above the high water mark and outside the taro bogs. The flowers are woven into leis, the leaves are important in love magic and to flavor overripe breadfruit (although the leaves themselves are not eaten), and the wood forms one of the most widely used fuels. In days when commercial matches were unknown or unavailable, wood from this plant was used to make a drill for starting fire by friction (cf. Girschner 1912:141). Leaves of "yeaar" covered with bumps are used to wash skin to get rid of pimples. Namoluk I. Marshall 12 (US); "yeaar;" G.

Stachytarpheta urticifolia Sims

Found growing in a cleared area near a path; no local uses. Namoluk I. Marshall 66 (US); no local name.

LABIATAE

Coleus scutellarioides (L.) Benth

Although one variety of coleus was introduced by Marshall in December 1969 and grew only outside his house, other varieties were to be found growing to a height of 1 to 1 1/2 meters along-side wells in the middle of Namoluk Islet. The juice of the leaves sometimes is squeezed onto cuts to retard bleeding. Namoluk I. Marshall 6 (US), 56 (US); "karamat" (Coleus).

Ocimum sanctum L.

This delightfully fragrant herb is planted in sunny cleared spaces adjacent to people's dwellings. The pungent flower stalks are plucked for leis and for use in locally manufactured perfume; they also play a role in love magic, and sometimes are introduced as a spice into fish or crab soup. Namoluk I. Marshall 4 (US); "warung;" G.

SOLANACEAE

Capsicum frutescens L.

Planted near people's houses as a condiment food. Several different colors of fruits may be found on varieties growing on Namoluk. The hot peppers are eaten (especially with raw fish) and sometimes are included in leis. Namoluk I. Marshall 5 (US), 8 (US); "mwik."

SCROPHULARIACEAE

Bacopa procumbens (Mill.) Greenm.

Found in the main taro swamp growing in a clump along with Hedyotis biflora. The plant has no local uses. Namoluk I. Marshall 104 (US); no local name.

Lindernia antipoda (L.) alst.

Growing in the taro swamp; no local uses. Namoluk I. Marshall 82 (US); no local name.

ACANTHACEAE

Barleria cristata L.

Only one specimen of this low bush occurs on the atoll, planted next to a person's house. It was introduced sometime after 1958 from the Truk Agricultural Station on Moen, Truk. Namoluk people have not devised a use for this plant. Namoluk I. Marshall 57 (US); no local name.

RUBIACEAE

Guettarda speciosa L.

Most of these trees grow a few meters above the high water mark in rough, rocky terrain. The long, white, tubelike flowers have an exquisite fragrance and are much sought for leis. The leaves occasionally serve to wrap food for cooking, as disposable plates, and to cover food in an earth oven. "Mosor" wood has a variety of uses, among them: firewood; saplings used in building construction, as poles for poling canoes, for fences and as markers to taboo land or reef sections; formerly, branches were used in fire by friction drills (cf. Girschner 1912:141) and today the wood is used for canoe paddles. Finally, the bark, flowers, and fruit are constituents of herbal medicines. Namoluk I. Marshall 52 (US); "mosor;" G.

Hedyotis biflora (L.) Lam?

Specimens were collected both from a shaded area in a path and from the taro swamp. The entire plant has medicinal uses. Its Namoluk name means 'smells like feces'. Namoluk I. Marshall 23, 103 (US); "alou mach."

Ixora casei Hance

This lovely bush, festooned with huge pompoms of bright reddish-orange flowers at the tip of each branch, grows plentifully in shady overgrown areas toward the middle of the islets. The supple

branches are bent into rims for the special nets made to capture flying fish; as straight sticks the branches are used by children in a local game called "apis". Occasionally, the flowers are used in leis and the blooming branches may be used for Christmas decor. The stem, bark and flowers are used in medicine. Namoluk I. Marshall 69 (US); "achiou;" G.

Morinda citrifolia L.

Grows everywhere from above the high water mark to the edge of the taro excavations; may reach a height of 10 meters. Although the plant is not cultivated, its fruit is eaten regularly. Saplings of "nin" are used in canoe house, cook house and fence construction, are cut as taboo ("pwau") markers for sections of reef, and the wood is a plentiful fuel. When breadfruit seeds are cooked in an earth oven, they are covered with "nin" leaves, and the leaves also are used to wrap eggs for roasting on a fire. The roots of very young "nin" plants formerly were ground up as a substitute for cosmetic tumeric when no tumeric was available. Tumeric was not produced on the atoll and was obtained on trading voyages by sailing canoe from the high islands in Truk Lagoon. Girschner reports that root bark of this plant was an ingredient in locally produced red dye (1912:158). Young branches bearing only a few immature leaves are employed in a kind of magic called "amaras" designed to make a thief admit his guilt and return what he has stolen; the same part of the tree is used in love magic ("auwar") and in a kind of defensive black magic known as "pwelipwel." "Nin" also is used in many medicinal preparations. The fruit is an ingredient in a local cough medicine, the leaves are singed over a fire and rubbed on itchy skin, and the roots of young "nin" plants were peeled and the shavings added to different medicines. In massage ("rewa") treatment for a person who has received a sharp blow (e.g., one who has been hit by a coconut, fallen from a tree or taken a strong punch in a fight), the massage master will manipulate the injured area and forbid the victim to eat roasted food. When the treatment has been completed, the massager will roast a "nin" fruit, slice it thin, and have the injured person and all those who regularly eat with him partake of it as a lifting of the taboo. At least one variety of "nin" growing on Namoluk was imported from Etal Atoll during the 1950s because of its larger fruit (96). Namoluk I. Marshall 9, 96 (US); "nin;" G.

GOODENIACEAE

Scaevola taccada (Gaertn.) Roxb. (glabrous form)

These tall shrubs form a standard part of the beach strand vegetation on all the islets. Wood from exceptionally tall plants may be used as poles for poling canoes and in building construction. Smaller branches are cut as markers to taboo sections of reef. The pleasantly fragrant flowers are a regular constituent of leis.

Medicinally, the white ripe berries are squeezed for their juice which is trickled into a person's eyes to relieve the sting of salt water. The flowers and white heartwood also are used in medicine. Namoluk I. Marshall 55 (US); "net;" G.

COMPOSITAE

Eclipta alba (L.) Hassk.

Found growing only in the taro swamps. No local uses. Namoluk I. Marshall 91 (US); no local name.

Wedelia biflora (L.) D.C.

This plant is found most frequently near the beach, but it seems to grow all over the islets in relatively cleared areas outside the taro bogs. The leaves serve as mulch for Colocasia esculenta, and the entire plant is used in magic to assure that a canoe will not break apart at sea; it also is an ingredient in medicines. Namoluk I. Marshall 33 (US); "etiet;" G.

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Table 1. Information on Pacific currents revealed by messages contained in bottles that drifted to Namoluk Atoll during 1970.

Date dropped	Date found on Namoluk	Total elapsed drift time	Location dropped	Location of Namoluk Atoll	Vessel from which dropped	Person dropping message
24 Nov. 1968	9 May 1970	531 days	Lat. 22° 37' N. Long. 107° 44' W.	Lat. 5° 55' N. Long. 153° 08' E.	Auxiliary ketch yacht Novia del Mar	John P. Scripps Scripps Bldg. San Diego, CA USA 92101
18 Mar. 1969	9 May 1970	417 days	Lat. "crossing equator" Long. 158° W.	Lat. 5° 55' N. Long. 153° 08' E.	S.S. Monterey	Charles E. Karnes 415 W. Newmark Ave. Monterey Park, CA USA 91754
5 Nov. 1969	29 Aug. 1970	297 days	Lat. "crossing equator" Long. 165° 28' W.	Lat. 5° 55' N. Long. 153° 08' E.	S.S. Monterey	F.S. Thompson 4914 Calle Jabali Tucson, AZ USA 85711

Source: Marshall, field research.

Table 2. Monthly Rainfall and Temperature Data for Namoluk Atoll from 1 January 1970 to 31 July 1971.

Month	Year	Temperature in degrees Centigrade HiHi	LoHi	HiLo	LoLo	AvHi	AvLo	Rainfall in millimeters Total rain	Heaviest 24 hr. rain	Days no rain
Jan.	1970	34	28	28	24	31	25.5	275.1	63.2	5
Feb.	1970	35.5	28	28	24	31	26	184.9	49.5	10
Mar.	1970	36	29	28	25	32	27	65.5	18.5	14
April	1970	39	28	28	24	33	26	238.5	48.0	9
May	1970	39	28	27	24	34	25.5	315.5	61.0	1
June	1970	40	30	28	24	35	25.5	282.4	62.2	4
July	1970	41	30	28	24	36	26	231.9	58.9	11
Aug.	1970	39	28	27	23	34	25	509.0	105.4	5
Sept.	1970	39	29	28	23	34	25.5	342.9	129.3	5
Oct.	1970	37	28	27	23	33	25.5	417.6	71.1	5
Nov.	1970	35	27	28	24	32	25.5	332.0	41.1	6
Dec.	1970	39	29	28	23	30	25.5	353.6	41.9	2
Annual	1970	41	27	28	23	33	25.5	3548.9	129.3	77
Jan.	1971	35	27	28	24	32	25.5	406.4	76.2	10
Feb.	1971	35	27	27	24	32	25	406.9	74.9	4
Mar.	1971	38	29	26	22	34	25	312.2	73.7	8
April	1971	37	27	27	24	33	25.5	314.7	71.1	2
May	1971	36	27	27	23	33	25.5	404.6	106.7	2
June	1971	42	27	27	23	35.5	25	343.9	50.8	1
July	1971	39	26	25.5	23	33	24	564.1	85.1	2
7 month totals	1971	42	26	28	22	33	25.5	2752.8	106.7	29

Source: Marshall, field research.

2 From Töinom Islet looking across to Umap Islet with tip of Amwes Islet in the distance. June 1971. Mac Marshall.

3 Mangrove forest, lagoon shore, Amwes Islet. June 1971. Mac Marshall.

4 *Bruguiera gymnorhiza* growing on open reef between Amwes and Umap Islets. June 1971. Mac Marshall.

5 Forested interior, Amwes Islet, showing Asplenium nidus growing on Artocarpus. June 1971. Leslie B. Marshall.

6 Forested interior, Namoluk Islet, showing abundant growth of Nephrolepis. June 1971. Leslie B. Marshall.

7 Sandspit (called "Pieman" locally) at the southwest tip of Amwes Islet. June 1971. Leslie B. Marshall.

8 Forest of <u>Pemphis acidula</u> on Tōinom Islet. June 1971. Mac Marshall.

9 Lagoon beach on Lukan Islet. June 1971. Leslie B. Marshall.

10 Lagoon shoreline of Töinom Islet with Amwes Islet in the distance. June 1971. Leslie B. Marshall.

11 Forested interior, Namoluk Islet, showing typical dense growth and underbrush. June 1971. Mac Marshall.

12 Amwes Islet, looking east from the long sandspit at the southwest tip (see plate 7). June 1971. Mac Marshall.

13 Mangrove forest along the lagoon shore of Amwes Islet. June 1971. Leslie B. Marshall.

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ATOLL RESEARCH BULLETIN

190. ALMOST-ATOLL OF AITUTAKI: REEF STUDIES IN THE COOK ISLANDS, SOUTH PACIFIC

Edited by D. R. Stoddart and P. E. Gibbs

Issued by
THE SMITHSONIAN INSTITUTION
Washington, D.C., U.S.A.

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Reef Studies in the Cook Islands, South Pacific

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PREFACE

The work reported here was accomplished during the Cook Bicentenary Expedition in August and September 1969. It could not have been carried out so fully in the time available without the support of the Cook Islands Government through the Premier, Hon. Albert Henry. The late Mr L. Peyroux acted as Expedition Liaison Officer with the Premier's Office. We are also grateful to the New Zealand High Commission; to the Rev. Bernard Thorogood and other members of the Cook Islands Library and Museum Association and to Mr Dawson Murray of Teriora College, on Rarotonga; and to Mr J.J. MacCaulay (Resident Agent), Mr Mokoenga Kavana (Acting Resident Agent), Mr Matai Simeona (Chairman of the Island Council), Mr Teariki Pera (Public Works Department), Mr and Mrs K. Buchanan, and many other people on Aitutaki, for their kindness and assistance. We thank Mr G. Markham and his staff, Royal Society of New Zealand; Mr Skam, Auckland Development Company; and Mr G.E. Hemmen, for their aid; and Mr E. Dawson, leader of the Expedition, and other members, and the Captain, Officers and Men of H.M.N.Z.S. Endeavour for their co-operation and assistance. We are most grateful to the Royal Society and to the Royal Society of New Zealand for the opportunity to take part in the Cook Bicentenary Expedition and to work in the Cook Islands.

We also thank those specialists who have worked on our collections and who have thus contributed to our report. These include W. Cernohorsky (Auckland Institute and Museum), Miss A.M. Clark (British Museum (Natural History)), F.R. Fosberg (Smithsonian Institution), W.R. Philipson (University of Canterbury, Christchurch), C.S. Gopinadha Pillai (Central Marine Fisheries Research Institute, Cochin, India), C.C. Townsend (Royal Botanic Gardens, Kew, Richmond, England), and J.C. Yaldwyn (The Dominion Museum, Wellington, New Zealand). Radiocarbon dates reported in Chapter 2 were provided by Dr K. Kigoshi, Gakushuin University, Japan, and were obtained with a grant from the Scientific Investigations Grants-in-Aid of the Royal Society. We thank Mr M. Young, Mr W. Kirkland, Mr R. Coe and Mr F. Whitham for their help with cartography, xeroxing and photography during the preparation of the report, and Mr M. Diver for his work on sediment samples at the Department of Geography, Cambridge.

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CONTRIBUTORS

F.R. FOSBERG
The Smithsonian Institution,
Washington, D.C. 20560,
U.S.A.

P.E. GIBBS
Marine Biological Association of the U.K.,
Plymouth,
England.

D.R. STODDART
Department of Geography,
Cambridge University,
Cambridge, England.

C.C. TOWNSEND
Royal Botanic Gardens,
Kew, Richmond, Surrey,
England.

H.G. VEVERS
Zoological Society of London,
Regent's Park,
London, N.W.1., England.

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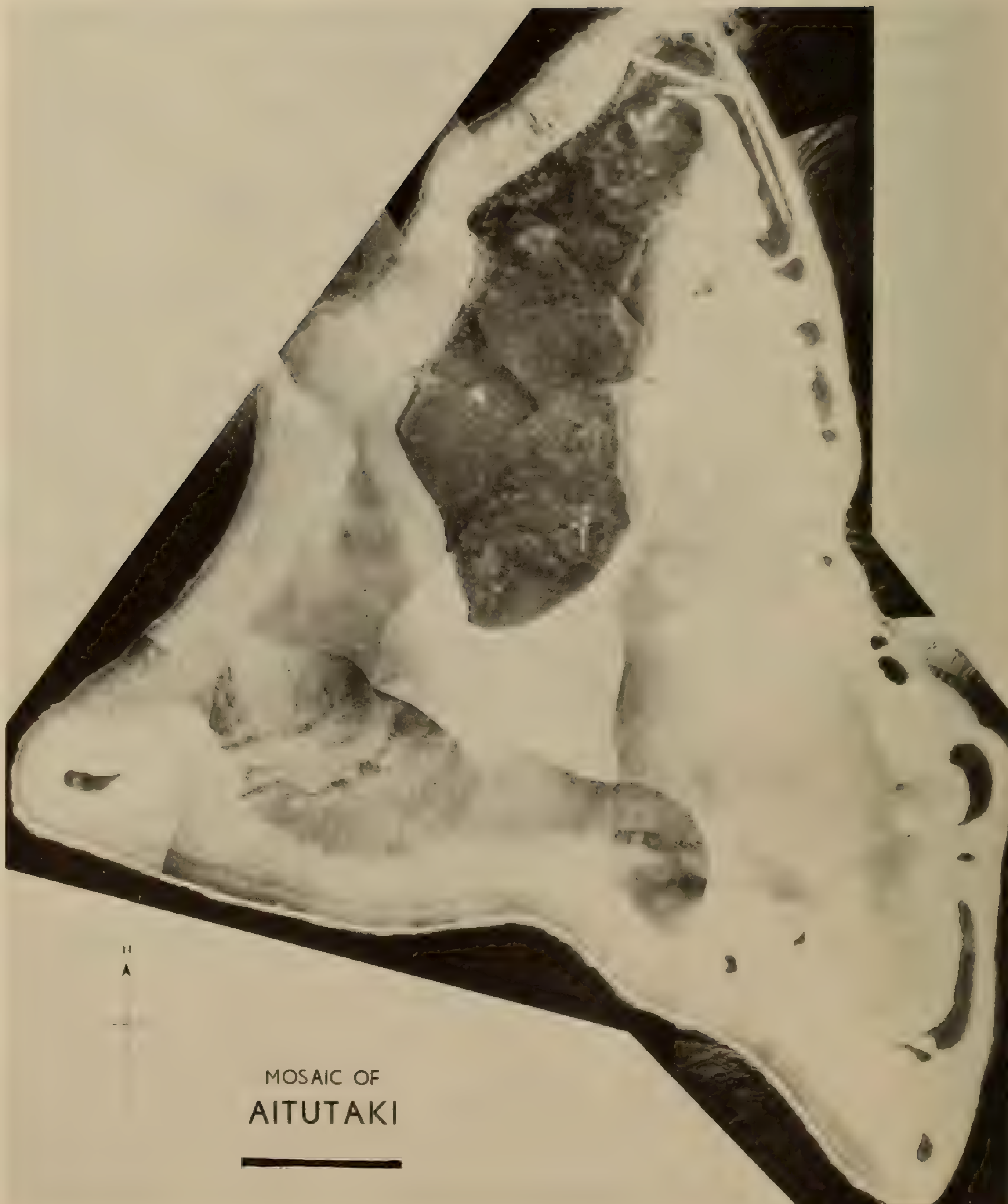

Frontispiece Airphoto mosaic of Aitutaki.
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1. SCIENTIFIC STUDIES IN THE SOUTHERN COOK ISLANDS: BACKGROUND AND BIBLIOGRAPHY

D.R. Stoddart

INTRODUCTION

The Cook Islands, in the centre of the Pacific (Figure 1), are remote from centres of recent reef studies in the Marshall Islands and the Tuamotus. The early work of Ladd in Fiji, Hoffmeister in Tonga, Mayor in Samoa, and Crossland and Setchell in Tahiti, served to indicate the existence of gradients of faunal and floral diversity across the central Pacific from west to east, a diversity reflected in the structure and composition of the reefs and also in terrestrial ecology, but in the absence of further detailed studies these gradients could be only loosely defined. The Cook Islands are of interest too, as Darwin and later workers recognised, for their combination of reef-encircled volcanic islands, almost-atolls, and atolls, and for the existence of several islands of elevated karst-eroded limestone locally known as *makatea*. These structures have implications for general theories of coral reef development, and they also promise new evidence on the problems of recent sea-level fluctuations in the open Pacific. It thus appeared timely to re-examine the Cook Islands, and the Cook Bicentenary Expedition in 1969, organized by the Royal Society of New Zealand, provided the opportunity to study shallow-water marine communities and some aspects of the terrestrial ecology of reef islands at Aitutaki and at Rarotonga.

These studies are reported in the present *Bulletin*, and this introductory paper describes the salient features of the southern Cooks, outlines the scientific work already carried out there, and presents a bibliography, by way of introduction to the more detailed papers which follow.

STRUCTURE AND TOPOGRAPHY

The southern Cook Islands (Figure 2) consist of a linear series of volcanic and limestone islands extending for 250 km from Mauke to Aitutaki, and the two more isolated islands of Rarotonga and Mangaia, all rising from the sea floor at depths of 4500-5000 m. A detailed chart of the area at 1:1,000,000 with contours at 1000 m intervals has been published by Summerhayes (1969), and an interpretation of the regional bathymetry has been provided by Summerhayes (1967). Robertson and Kibblewhite (1966) have drawn attention to the similarity of the submarine slope profiles of volcanic islands and of atolls with no volcanic rocks now exposed at the surface. The

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southern Cook Islands appear to comprise a series of volcanoes of different ages, some recent, with narrow fringing reefs (such as Rarotonga), others capped with thickness of limestone and subsequently elevated to form a karst surface locally known as makatea. In the northern Cooks the process of atoll development by Darwinian subsidence has proceeded further, and true atolls such as Manihiki and Palmerston have been formed. There is no direct evidence of the depth to volcanic basement beneath these atolls, but seismic data at Manihiki indicates a dome-shaped basement with volcanic rocks at 0.5 km depth beneath the peripheral reef but at only 0.05 km in the centre of the lagoon. Aitutaki, as an almost-atoll, is presumably intermediate in age between the northern atolls and islands such as Rarotonga.

Rarotonga and Aitutaki form the summits of separate volcanic masses rising from depths of 4000 m, at which depth the cones are 45-55 km in diameter (Summerhayes and Kibblewhite, 1966, 1967). The lower slopes of the cones average 15-25°, increasing to 30° in the upper 750 m and becoming very steep as the surface reef is approached. The Mauke-Aitutaki line of islands is thought to be of early Tertiary age: the surface volcanics are much eroded, with a subdued topography, or are capped with limestones (Wood, 1967; Wood and Hay, 1970). On Rarotonga, where the relief is much stronger (maximum altitude 640 m), radiometric ages of 2.3-2.8 million years date the lavas as Pliocene (Tarling, 1967). Mangaia, with a cap of Oligocene-Miocene limestones, must be much older (Marshall, 1927). Evidence from the deep-sea drilling programme indicates that the ocean floor in the area of the southern Cooks is Paleogene (22.5-65 million years) in age (Winterer, 1973), thus providing a maximum age for the islands. It is probable that the gross history of the Cooks resembles that of other, better-known reef-capped Pacific volcanic cones known to have been initiated in the early Tertiary.

Aitutaki (lat. 18°51'45"S, long. 159°48'10"W), 225 km north of Rarotonga, is an almost-atoll with a total area of 106 km^2 (Figure 3). The main volcanic island, located excentrically on the northwestern reef rim, has an area of 16.8 km^2 and rises to a maximum height of 119 m. It is thus a much more extensive volcanic residual than that of the only other almost-atoll recently studied, Clipperton in the east Pacific (Sachet, 1962). In addition to the main volcanic island, basalts and agglomerates also outcrop on Aitutaki near the southern reef rim in the islets of Rapota and Moturakau. On the latter the agglomerates include coral fragments, indicating that the later stages of volcanism were contemporary with reef growth. A similar situation has been described for reef-edge volcanic islets at Mayotte in the Comores by Guilcher et al. (1965). The situation at Aitutaki thus contrasts with that in the other makatea islands of the southern Cooks, where vulcanicity had evidently ended before deposition of the limestone caps had begun. Age estimates of the Aitutaki volcanics range from

Eocene to Miocene-Pliocene (Wood and Hay, 1970, pp.36-40).

The peripheral reefs of Aitutaki are roughly triangular in shape, enclosing a lagoon with a total area of about 50 km^2 and with a maximum depth of 10.5 m. Detrital reef islands are concentrated along the eastern (windward) reef, and have a total area of about 2.2 km^2. Seismic refraction measurements by Hochstein (1967) indicate a thickness of coral limestone over basalt of 13-20 m in the Ootu Peninsula, adjacent to the main volcanic island, and of 150±30 m at Tavaerua Iti, midway along the eastern reef. Results of gravity surveys at Aitutaki are reported by Robertson (1970), and of magnetic surveys by Lumb and Carrington (1971).

Rarotonga (lat. 21°12'06"S, long. 159°46'33"W) is a larger and more deeply dissected mountainous island, 250 km^2 in area, with maximum dimensions of 8 x 11.5 km, and a maximum elevation of 652 m. The geology has been described by Marshall (1930) and by Wood and Hay (1970, 10-27). The Pliocene volcanic core is surrounded by Pleistocene gravels and sands of different ages, with remains of a slightly elevated coral reef. The modern reefs are fringing and of variable width. In the east, at Ngatangiia, the reef encloses a deeper channel and there are three small sand cays and a volcanic islet standing on it; these have been described elsewhere (Stoddart, 1972). In addition to the radiometric dating, geomagnetic studies have been reported by Woodward and Hochstein (1970) and gravity data by Robertson (1967).

CLIMATE

Aitutaki and Rarotonga both lie in the Southeast Trades, and are influenced by winds from the northeast, east and southeast throughout the year (Hydrographic Office, 1966). Maximum rainfall occurs during December-March, when the Trades are less steady, and squalls and northerly winds may occur (Figure 4).

Table 1 summarises rainfall data for Aitutaki: monthly rainfalls for 1930-1971 are given by Taylor (1973) and incomplete records for 1907-1911 by Hunt (1914, 255). Mean annual rainfall is 1984 mm, rather more than half of which occurs during December-March (Figure 5). This compares with 2103 mm at Rarotonga (where, however, there is considerable local variability because of orographic effects), 2482 mm at Manihiki, and 2984 mm at Pukapuka in the north. Figure 6 shows histograms of the annual rainfall distribution at these stations. All show a similar seasonal pattern, though the dry season is most marked at Aitutaki, especially in June-September. According to K.M. Johnston (1967, p.74), on occasions no rain may fall for over a month. Johnston calculated Thornthwaite potential evapotranspiration figures for Aitutaki, confirming the existence of the pronounced dry season.

Table 2 and Figure 7 give temperature records for Aitutaki. The mean annual temperature is 25.6°C. Mean daily maxima exceed 30° during January-April, and mean daily minima fall below 22° during June-October. The highest temperature recorded is 37.2° and the lowest 12.8°. The range in mean monthly temperatures is 3.4°, the daily temperature range is about 11°.

Table 3 gives relative humidity data for Aitutaki at 0900 and 1430. These show a similar seasonal trend to rainfall and temperature.

The main source for climatic data is in K.M. Johnston (1967, pp.71-75), based on 37 years of records maintained by the Meteorological Service, Wellington; Tables 2-4 are based on Johnston's data. Slightly different figures are given by Tamashiro (1964), particularly for rainfall and number of raindays. Summaries of climatic data for the Cook Islands, including the northern atolls, are given in Maps of the Cook Islands (Survey Department, Rarotonga), and for rainfall by Taylor (1973).

Hurricanes

The southern Cook Islands lie within the South Pacific hurricane belt, but because of the paucity of records and the scattered distribution of climatic stations, even compared with the area to the west, little is known of hurricane tracks or frequency. Most studies of south Pacific hurricanes concentrate on the southwest Pacific area and terminate at 160°W, the longitude of the Cooks. Hutchings (1953) contributes a general discussion of south Pacific hurricanes, but with few specific records. The fullest listing for the Cooks is still that given by Visher (1925, 40), but this omits a number of severe storms reported in the early missionary accounts. Table 4 lists the recorded storms, based on Visher's lists with additions; it is certainly incomplete, especially for the present century. It is, however, clear that storms of exceptional severity have occurred in the southern Cooks during the last 150 years. They occur mostly during January-March, and approach from the north-east, curving round to the south and the northwest. Being in the southern hemisphere the hurricane winds rotate clockwise about the centre.

MARINE ENVIRONMENT

According to standard sources on the oceanography of the South Pacific (Fiziko-Geograficheskiy Atlas Mira, 1964), the mean sea surface temperature in the southern Cook Islands ranges from 27.3°C in January to 25.5°C in June.

Table 1. Rainfall at Aitutaki

Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean monthly rainfall, mm	228.9	286.3	242.3	157.7	141.5	104.6	79.8	79.5	82.0	133.9	188.2	259.3	1984
Mean number of rain days	13	14	10	10	9	8	9	7	8	9	11	13	120
Number of months with less than 61 mm (2.4 in) 1920-60	4	2	-	10	11	20	20	27	20	14	8	1	
Number of months with less than 61 mm as percentage	10	5	-	25	27.5	50	50	67.5	50	35	20	2.5	

Source: K.M. Johnston, 1967

Table 2. Temperature at Aitutaki (^{o}C)

Month	Mean daily temperature	Mean daily maximum	Mean daily minimum	Highest recorded	Lowest recorded
Jan	27.2	30.6	23.9	35.0	17.8
Feb	27.2	30.6	23.9	35.6	17.8
Mar	27.2	30.6	23.9	34.4	20.0
Apr	26.7	30.0	22.8	33.9	16.1
May	25.6	28.9	22.2	31.7	16.7
Jun	24.4	27.8	20.6	31.7	15.6
Jul	24.4	27.8	21.1	31.1	12.8
Aug	23.9	27.2	20.6	31.1	15.0
Sep	24.4	28.3	21.1	31.1	15.0
Oct	25.0	28.3	21.7	37.2	14.4
Nov	26.1	29.4	22.8	32.2	17.8
Dec	26.7	29.4	23.3	33.3	17.8
Means	25.6	28.9	22.2		

Source: K.M. Johnston, 1967, p.71

Table 3. Mean relative humidity at Aitutaki (per cent)

Local time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
0900	80	83	82	81	80	80	79	78	77	75	77	80	79
1430	73	73	73	73	71	68	64	67	70	70	71	72	71

Source: K.M. Johnston, 1967, p.71

Table 4. Hurricanes in the Cook Islands

	Date	Comment
1831	21 December	Rarotonga
1839	22 February/1 March	
1841	February	Rarotonga
1841	17 December	Rarotonga; "gigantic waves"
1842	15-18 December	
1845	16-17 January	
1846	16-18 March	
1848	24 December	
1854	6 February	Rarotonga; hurricane and earthquake (Gill, 1856, 224-5)
1865	25 January/3 February	
1869	4-5 April	
1877	24 February	Towards Austral Islands
1882	2 February	Towards Austral Islands
1882	18 March	Towards Austral Islands
1883	December	Palmerston Island
1887	10-11 April	Towards Austral Islands
1889	18 February	
1890	15 December	Towards Austral Islands
1897	10-11 February	
1923	8 March	Towards Kermadec Islands
1943	4 March	
1946	10 January	

Source: Visher, 1925, p.40; Hutchings, 1953; Gill, 1856

Tides are semi-diurnal and of small amplitude. At Aitutaki the range at springs is 0.49 m and at neaps 0.12 m, and at Rarotonga 0.82 m at springs and 0.24 m at neaps. There is no substantial inequality between successive high and low tides in the semidiurnal cycle.

Tsunamis occur in this area but no major ones have been recorded. Keys (1963) describes the tsunami of 22 May 1960, which was observable at Rarotonga. In this case the small effect may be attributed in part to the fact that the tsunami arrived at a stage in the tidal cycle when the sea was below the level of the reef flat. Tsunamis in the Cooks are much less important than hurricanes in causing coastal inundation.

RECENT HISTORY OF AITUTAKI

Human activities have clearly had a profound effect on the ecology of islands in the southern Cook Group, not only during the one and a half centuries of direct European influence, but also during the earlier period of Polynesian colonisation and settlement. No detailed studies have been made of these effects, and indeed the history of human occupation itself is known only in bare outline. The main sources for pre-Contact history are in oral tradition, initially collected by missionaries such as Wyatt Gill (1876, 1880, 1885, 1894), and accounts of the initial settlement of Rarotonga and Aitutaki from these sources have been provided by Best (1927) and Pakoti (1895). Archaeological work has been begun by Duff (1968, 1971) and Bellwood (1969, 1971, 1973). Beaglehole (1957), Crocombe (1964) and Curson (1973) have presented recent summaries of the pre-contact and early contact periods, and these serve as a basis for the present account.

Cook discovered Manuae during his second voyage in 1773, and Mangaia and Atiu during his third in 1777, but he did not locate either Rarotonga or Aitutaki. Aitutaki was discovered by Europeans on 11 April 1789, when Captain William Bligh arrived on H.M.S. Bounty, before the mutiny. Bligh (1792) briefly but recognisably described the island:

> "...on the 11th, at daylight, land was seen to the S S W, at about five leagues distance, which appeared to be an island of a moderate height. On the north part was a round hill: the northwest part was highest and steep: the southeast part sloped off to a low point. ...we tacked to the southward, and, as we advanced in that direction, discovered a number of low keys, of which at noon we counted nine: they were all covered with trees. The large island first seen had a most fruitful appearance, its shore being bordered with flat land, on which grew innumerable cocoa-nut and

other trees; and the higher grounds beautifully interspersed with lawns. ... On the 12th ... at two in the afternoon, we were within 3 miles of the southernmost key. ...the name of the large island ... was Wytootackee.

The island of Wytootackee is about ten miles in circuit; its latitude from 18°50' to 18°54'S, and longitude 200°19'E. A group of small keys, eight in number, lie to the S E, 4 or 5 miles distant from Wytootackee, and a single one to the W S W; the southernmost of the group is in latitude 18°58'S. Variation of the compass 8°14'E" (Bligh, 1792; 1961 edition, 127-129).

The Pandora, Captain Edwards, called on 19 May 1791, while searching for the Bounty mutineers (Edwards, 1915), and on 25 July 1792 Bligh himself again passed by in the Providence. These early contacts can have had little direct effect on Aitutaki. After the Bounty mutiny, the ship, under Fletcher Christian, apparently called at Rarotonga in 1789; the missionary John Williams (1837) reported a tradition of this visit surviving in 1823, and Christian thus becomes the discoverer of Rarotonga. No other ships called there until 1813 and 1814. Captain Theodore Walker in the Endeavour sighted the island and Captain Goodenough in the Cumberland landed there, searching for sandalwood, and Goodenough is said to have cut a great deal of nono (Morinda citrifolia) in mistake for it at Ngatangiia (Gill, 1856; Gosset, 1940; Maude and Crocombe, 1952). Goodenough subsequently called at Aitutaki (August 1814) and set down a group of Rarotongans he had abducted. The Seringapatam also called at Rarotonga, on 23 May 1814, and was followed by other vessels (Coppell, 1973).

Effective contact began with the arrival on Aitutaki of the Rev. John Williams on 26 October 1821. He left native Tahitian missionaries there, and went on to do the same at Rarotonga, having learned of the existence of the latter island from Goodenough's Rarotongans. When Williams returned to Aitutaki in July 1823, the inhabitants had apparently been converted to Christianity. In 1827 he went back to Rarotonga, instituted a code of laws, and installed the first of a series of English missionaries - Charles Pitman at Ngatangiia (1827-1855), Aaron Buzacott at Arorangi (1828-1857), and William Gill (1839-1857). Narrative accounts of the early history of the Rarotonga missions are given by Buzacott (1866), Gill (1856, 1880), and Wyatt Gill (1876a, 1885). Much material on cultural change and the introduction of plants and animals is undoubtedly contained in archival material relating to these missions, notably the journals of Pitman (1827-42), Buzacott (1828-40) and Mrs Buzacott (1830-33), with a manuscript by the latter on life on Rarotonga in the 1830s, in the Mitchell Library, Sydney, and letters in the London Missionary Society archives, but it has

not been possible to explore this material in the present study. Beaglehole (1957, 45) has fully documented the progress of disease, occurrence of hurricanes, and social disruption during the first decades of European contact, which reduced the population from ca. 7000 in 1833 to about 2000 between 1845 and 1900: major factors in this decline were the new diseases of measles, whooping cough, mumps, influenza, jaundice and dysentery.

At Aitutaki the first English missionary, Henry Royle, arrived on 23 May 1839, by which time some European beachcombers were already living on the island. He remained there for about 35 years (Plates 1-2). The impact of contact was less catastrophic than on Rarotonga. Epidemics were less serious, though there were notable outbreaks of dysentery in 1843 and measles in 1854. The population declined from approximately 2000 when Royle arrived to less than 1200 in the forty years after 1880. In spite of the alleged early and complete conversion of the people, Royle had a difficult time: disturbances and arson in the early months were followed by serious hurricanes in February 1841 and again in December 1842. His problems were accentuated by the development of the central Pacific whaling industry, for which both Aitutaki and Rarotonga became important victualling stations: thus in 1843 no less than 35 ships called at Aitutaki, and 100 at Rarotonga. Numbers of islanders joined the vessels as crew members, and of course the whalers went ashore. Perhaps the most severe disturbance on Aitutaki, which Royle was powerless to control, occurred in 1847, when two whalers, one American, one French, were wrecked there, and 70 sailors spent a year on the island. It is not surprising that the missionaries took the view that "All runaway sailors were <u>profligate</u>, all Frenchmen <u>licentious</u>, all Roman Catholics <u>venal and corrupt</u>, all traders <u>petty and dishonest</u>" (Beaglehole, 1957, p.75). By the time that whaling declined in these waters in the 1860s, Peruvian slave vessels were cruising in the northern Cooks seeking guano workers, and Cook Islanders were leaving for Makatea and also for New Zealand. By this time the islanders were said to be all clothed, housed, and literate, and Royle was selling Testaments at Aitutaki at the standard rate of 18-20 lbs of arrowroot per copy.

The missionaries took a leading part in the introduction of economic crops and in the transformation of the indigenous economy. Cotton and the sweet potato were on Rarotonga before 1831: Buzacott introduced arrowroot, tapioca, rice and coffee, and also a weaver for cotton cloth. The cultivation of yams, bananas, pumpkins, pineapples and oranges, and the rearing of pigs and poultry were encouraged. Rum was introduced to Rarotonga in 1845, and methods of fermenting oranges, pineapples and bananas were known there by 1851. We have no details of the economic transformation at Aitutaki, but it presumably closely followed that at Rarotonga.

With the conclusion of the initial missionary phase and the economic development of the islands, and with increasing imperial interest in the Pacific, the political status of the Cook Islands required definition. A British Protectorate was therefore declared over Rarotonga, Aitutaki, Mangaia, Mauke, Mitiaro and Manuae on 22 September 1888 (Gilson, 1955). Administration was transferred to New Zealand in 1901. The main economic significance of the islands, linked by schooners, was as a source of copra and other coconut products, but the trade proved a highly variable one (Figure 8), being greatly affected by market fluctuations. After the initial missionary intervention, however, the second major event in the recent history of Aitutaki was the Second World War. When it began the island had a population of about 2000. In 1942 a party of 900 U.S. Marines, including 400 negroes, was established there, and remained until 1944 (K.M. Johnston, 1967). The present airstrip was built on the Ootu Peninsula. After the war a Solent flying boat service was operated by Tasman Empire Airways Ltd to Samoa, Tonga, Fiji and Auckland, and by UTA to New Caledonia and Tahiti. The landing area was in the southeast lagoon, with terminal facilities on Akaiami island, linked by launch with a mainland jetty at Tautu. This service was discontinued in 1960, but New Zealand military planes maintain a service from New Zealand via Rarotonga, using the Ootu landing facility. Marine communications were also improved during the war. The reef entrance at Arutanga was dredged and a stone jetty constructed. The jetty has now disintegrated, and the channel, 1.5 km long, carries less than 2 m water. No regular shipping service serves Aitutaki. Matson Line vessels callat Rarotonga, where a new commercial jet airfield has now been constructed. The increased accessibility and development of tourism which will result from this development will certainly lead to major changes in all aspects of life both on Rarotonga itself and on islands accessible from it, including Aitutaki.

It will be apparent that, in spite of the relatively short history of European contact, native life has been subject to major changes since the first missionaries arrived. Active anthropological and ethnological research, other than the often anecdotal records of the missionaries, did not begin until the 1920s: most of the studies, under the influence of Sir Peter Buck, concentrated on artefacts and material culture. In the southern Cooks, studies were made of Aitutaki (Buck, 1927) and Mangaia (Buck, 1934), and in the northern Cooks of Tongareva (Buck, 1932a), Manihiki and Rakahanga (Buck, 1932b), and Pukapuka (Macgregor, 1935; Beaglehole and Beaglehole, 1938). Summaries of the Cook Islands were proved by Buck (1944, 1945). Missionary accounts of Aitutaki traditions were supplemented by Low (1934, 1935).

In spite of these accounts, little is known of the economy and human geography of Aitutaki in pre-contact times. It is reported that villages were originally located at inland sites,

on hills, and only moved down to the coast under the influence of missionaries (Beaglehole, 1957, p.6). With the long history of Polynesian occupation, the size of the population in 1830, and the limited land area, it is clear that the landscape of Aitutaki must have been substantially influenced by man before the European discoveries. Population numbers provide a crude but effective index of the subsequent course of human activity. Table 5, based on McArthur (1968), gives census and pre-census population figures for Rarotonga and Aitutaki since 1821. The fall in numbers during the early years of missionary activity on both islands has already been noted. At the census in 1966 the population of Rarotonga was 9971, and of Aitutaki 2579. In the case of Rarotonga the total represents a density of approximately 780 per cultivated square mile, or 500 per mile of coast; in the case of Aitutaki, of 430 per cultivated square mile and 220 per mile of coast. Densely populated islands in the western Pacific, such as the Gilbert and Ellice Islands, the Carolines and Marshalls, have overall population densities of 160-180 per square mile. Largely because of migration the Aitutaki population has been stable over the last decade, whereas that of Rarotonga has increased since 1956 by over 50 per cent; that of atolls on the northern Cooks and of islands such as Mauke has decreased sharply (Curson, 1972). Concurrent changes in agriculture, with increasing emphasis on cash crops (citrus fruits, vegetables, tomatoes), have been treated in detail for Aitutaki by K.M. Johnston (1967).

The scale and intensity of these changes in the recent past must be remembered throughout the subsequent discussion of the vegetation and flora of Aitutaki, and of other aspects of the ecology of the Cook Islands. Remote and little studied as these islands are, they are in no sense unaffected by the work of man.

SCIENTIFIC STUDIES IN THE SOUTHERN COOKS

Though important observations were made by Cook and his companions, particularly on Palmerston Island in 1777 (Cook, 1967 edition, 92-96, 849-857, 1011-1012), little scientific work was carried out in any part of the group until more than a century had passed. Charles Darwin passed through the southern Cooks on the Beagle in 1835, but did not land. He sighted Aitutaki, and in a passage in his Diary (Darwin, 1933, 358-359), omitted in the published version in Journal and Researches (1839), notes:

> "December 3rd. After several days of light winds, we passed near to the island Whytootacke. We here saw a union of the two prevailing kinds of structure united. A hilly irregular mass was surrounded by a well defined circle of reefs, which in great part have been converted into low narrow strips of land, which as Cook calls them are half drowned, consisting merely of sand and Corall rocks heaped up on the dead

> part of a former reef. The inhabitants made a smoke to attract our attention."

Darwin was at this time drafting the first full statement of his coral reef theory, in which he mentions Aitutaki and speculates in which of his classes of reefs it should be placed (Darwin, 1962, p.7). In his Structure and Distribution of Coral Reefs (1842, pp.154-155), he discussed the matter more fully:

> "Aitutaki was partially surveyed by the Beagle, (see map accompanying Voyages of Adventure and Beagle); the land is hilly, sloping gently to the beach; the highest point is 360 feet; on the southern side the reef projects five miles from the land: off this point the Beagle found no bottom with 270 fathoms: the reef is surmounted by many low coral-islets. Although within the reef the water is exceedingly shallow, not being more than a few feet deep, as I am informed by the Rev. J. Williams; nevertheless, from the great extension of this reef into a profoundly deep ocean, this island probably belongs, on the principle lately adverted to, to the barrier class, and I have coloured it pale blue; although with much hesitation."

After Darwin's brief and distant observations, the only general scientific studies in the nineteenth century were the episodic and anecdotal notes made by the missionary Wyatt Gill. His "Notes on natural history" (Gill, 1877, pp.273-320) and "Zoological and botanical notes" (Gill, 1885, pp.125-210; also Gill, 1888) are, however, of little value. Otherwise the nineteenth century scientific literature is limited to an important paper on the land Mollusca by Garrett (1881), a description of two hydrozoans from Rarotonga by Quelch (1885), and a brief note on the marine algae of Mangaia by Dickie (1875).

Early in the present century, Marshall initiated a long series of studies of the volcanic rocks and elevated limestones of the southern Cooks, particularly of Rarotonga, Atiu and Mangaia (Marshall, 1908, 1909, 1912a, 1912b, 1927, 1930; Chubb, 1927). The reefs of Aitutaki were briefly visited by Alexander Agassiz (1900, 1903) in November 1899, though his observations proved to be characteristically unreliable. Crossland (1928c) and W.M. Davis (1928, pp.406-408) briefly described the reefs of Rarotonga. Crossland in particular published a long series of papers on Tahiti, several of which contain comparative comments on the reefs of Rarotonga (Crossland, 1927, 1928a, 1928b, 1928c, 1929, 1931a, 1931b, 1935, 1939). Agassiz, Davis and Crossland were all concerned with the geological relations of the reefs and their historical implications, rather than with reef biota and ecology: indeed no work seems to have been carried out on littoral marine ecology in the Cook Islands until recent years. Rather more work has been carried out on terrestrial

ecology. Floristic studies of Rarotonga were published by Luerssen (1873), Cheeseman (1903) and Wilder (1930, 1931), though no collections have been reported from Aitutaki or other islands in the southern Cooks. Taxonomic papers on the vascular flora have been published by Copeland (1931), Martelli (1932), Skottsberg (1933), Whitney (1937) and St John (1952), all based on Rarotonga material. Campbell (1932) has listed native names of Rarotongan plants. On other islands in the group, Hemsley (1884) named a few species collected by J.T. Arundel on Palmerston and Suvarov, and Cranwell (1933) gave a list of plants and Linton (1933) contributed brief notes on the vegetation of Manihiki. Lichens of Rarotonga are described by Jatta (1903-5) and Sbarbaro (1939) and Fungi by Karling (1968). The early literature on land animals is remarkably sparse, and with the exception of Garrett's work on land Mollusca and of Christian's (1920) paper on the birds of Mangaia is concerned with anthropods, especially mosquitoes of medical importance. Most of the studies are based on Rarotonga material, with some specimens from the northern Cooks, especially from Manihiki (Marks, 1951; Krauss, 1961; Taylor, 1967; Lieftinck, 1953; Laird, 1956; Tamashiro, 1964; Marples, 1960). The papers by Krauss (1961) and Laird (1956a) deal specifically with collections from Aitutaki. Solem (1972) has also recently published on a new land snail from Rarotonga.

The most important scientific studies in the Cook Islands in recent years have been those of the New Zealand Oceanographic Institute (Manihiki Expedition, 1960; Eclipse Expedition, 1965) and the Cook Bicentenary Expedition of 1969. The Eclipse Expedition carried out much bathymetric work throughout the group and established both regional and local data on submarine topography (Robertson and Kibblewhite, 1966; Summerhayes, 1967, 1969; Summerhayes and Kibblewhite, 1966, 1967, 1968, 1969). In addition E. Dawson and Summerhayes studied marine communities and bottom sediments at Aitutaki and Manuae (Summerhayes, 1971). Extensive collections were made during this expedition and are still being studied; the echinoderms have been listed by McKnight (1972). The results of the Manihiki expedition have been collected by Bullivant and McCann (1974).

The Cook Bicentenary Expedition of 1969 was a joint New Zealand and United Kingdom project working in the Cook Islands and Tonga (Fraser, 1971). The United Kingdom Marine Biology Party (Project 9) consisted of D.R. Stoddart, P.E. Gibbs, and H.G. Vevers. Its main project at Aitutaki concerned shallow water marine communities, geomorphology and sediments in reef, lagoon and beach environments, but it also extended to certain aspects of terrestrial ecology, notably the vegetation. A short supplementary study was also made of similar habitats at Ngatangiia Harbour, Rarotonga, with a subsequent reconnaissance of reefs and islands at Nuku'alofa, Tonga. The party worked on Rarotonga between 21 and 27 August 1969, and on Aitutaki between 27 August and 26 September 1969. A preliminary account of the

work was given by Gibbs, Stoddart and Vevers (1971). Gibbs (1972) has published on the polychaete annelids and Stoddart and Pillai (1973) on the corals collected. An account of the Rarotonga reef islands is given by Stoddart (1973), with a list of vascular plants by F.R. Fosberg. Ferns from these islands are included in Brownlie and Philipson's (1971) list of Cook Islands Pteridophyta. In addition to the papers in the present Bulletin, a more detailed account of the corals is in course of publication (Pillai and Stoddart, in press). A preliminary account of the terrestrial invertebrates of Rarotonga, Aitutaki and other islands has been given by Wise (1971).

Some of this work supplements the extensive studies of land geology carried out in August and September 1957 throughout the Group by B.L. Wood (1967; Wood and Hay, 1970). Work during the Cook Expedition on gravity and magnetics (Lumb and Carrington, 1971) also supplemented important recent geophysical studies: on magnetics by Woodward and Hochstein (1970) and Woodward and Reilly (1970), on gravity by Robertson (1970), on paleomagnetism on Rarotonga by Tarling (1967), and on seismic refraction studies by Hochstein (1967).

The soils of the southern Cooks have been studied by Grange and Fox (1953) and Stout (1971), and agriculture and land use by W.B. Johnston (1951, 1953a, 1953b, 1955, 1959), K.M. Johnston (1967), and Bassett and Thomson (1968).

Since the Cook Bicentenary Expedition the Group has been visited by the Westward Expedition from Honolulu, which spent 7-8 March 1971 at Aitutaki and 6-11 March at Rarotonga, making general collections and searching for the Crown-of-Thorns Starfish Acanthaster planci. Results of this survey, with information on the reefs, are presented by Devaney (1973) and Devaney and Randall (1973).

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Table 5. Population of Rarotonga and Aitutaki

Year	Rarotonga	Aitutaki
1821		ca 2000
1839		ca 2000
1845	3000	2000
1854-5	2374	1750
1871-2	1936	1450
1881	2000	1146
1902	2060	1170
1906*	2334	1154
1911*	2620	1221
1916*	2853	1277
1921*	3287	1343
1926*	3731	1417
1936*	4818	1707
1945*	5307	2332
1951*	5802	2358
1956	6417	2590
1961	8676	2582
1966*	9971	2579
1971*	11388	2854

*census return

Source: McArthur, 1968; New Zealand Official Yearbook (annual)

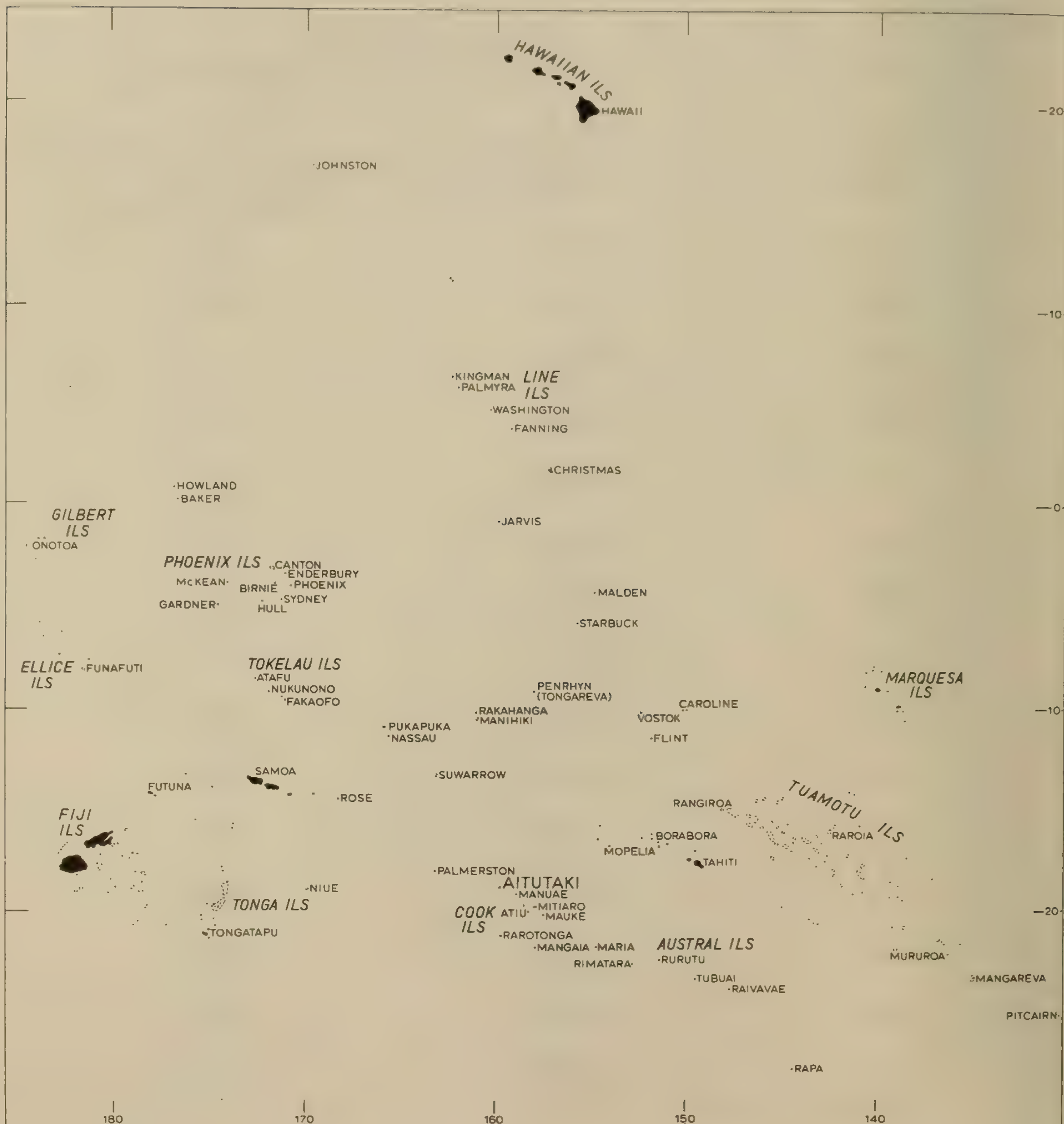

Figure 1. Location of Aitutaki in the central Pacific

Figure 2. Bathymetry of the southern Cook Islands, after Summerhayes (1967)

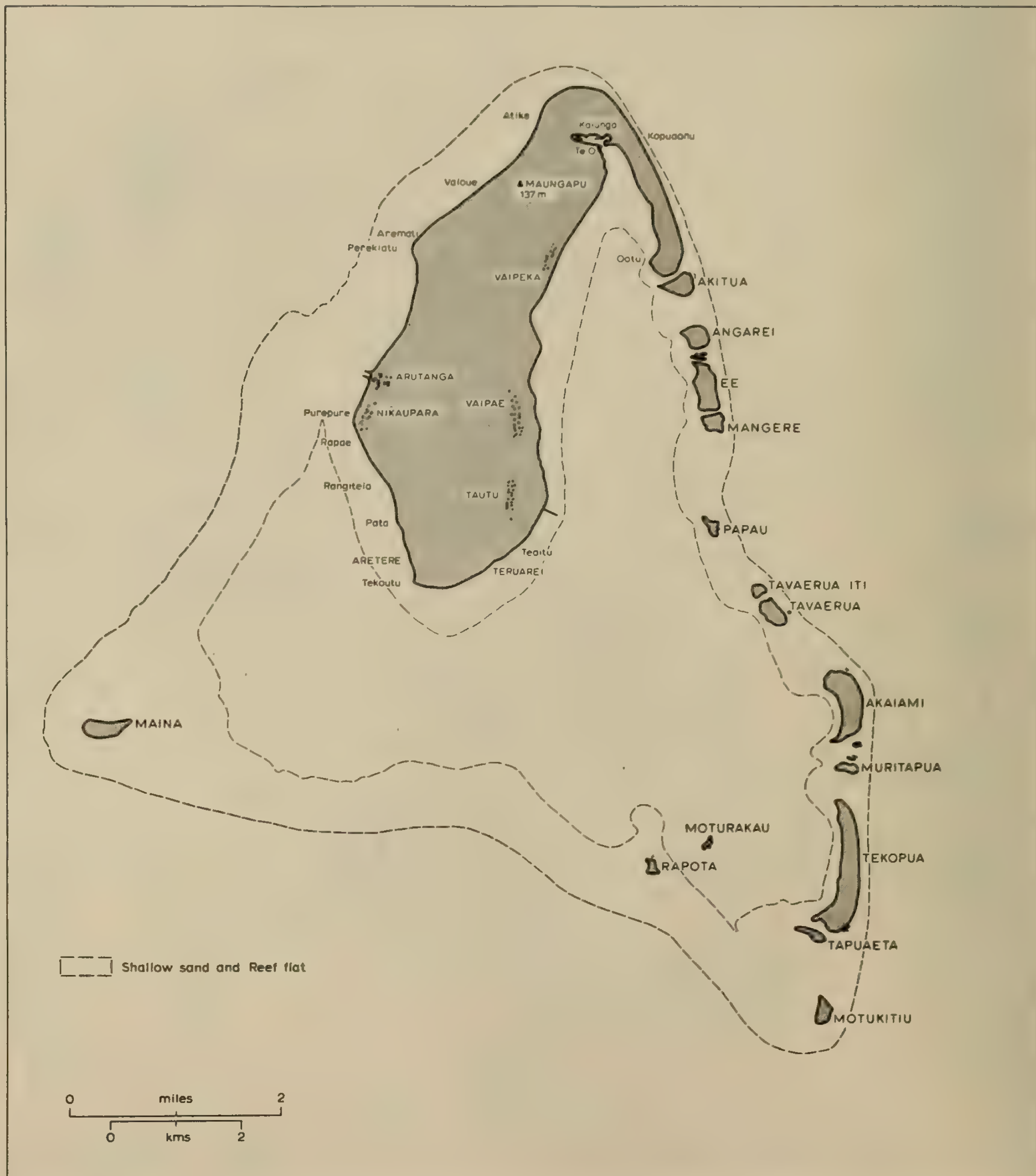

Figure 3. Aitutaki

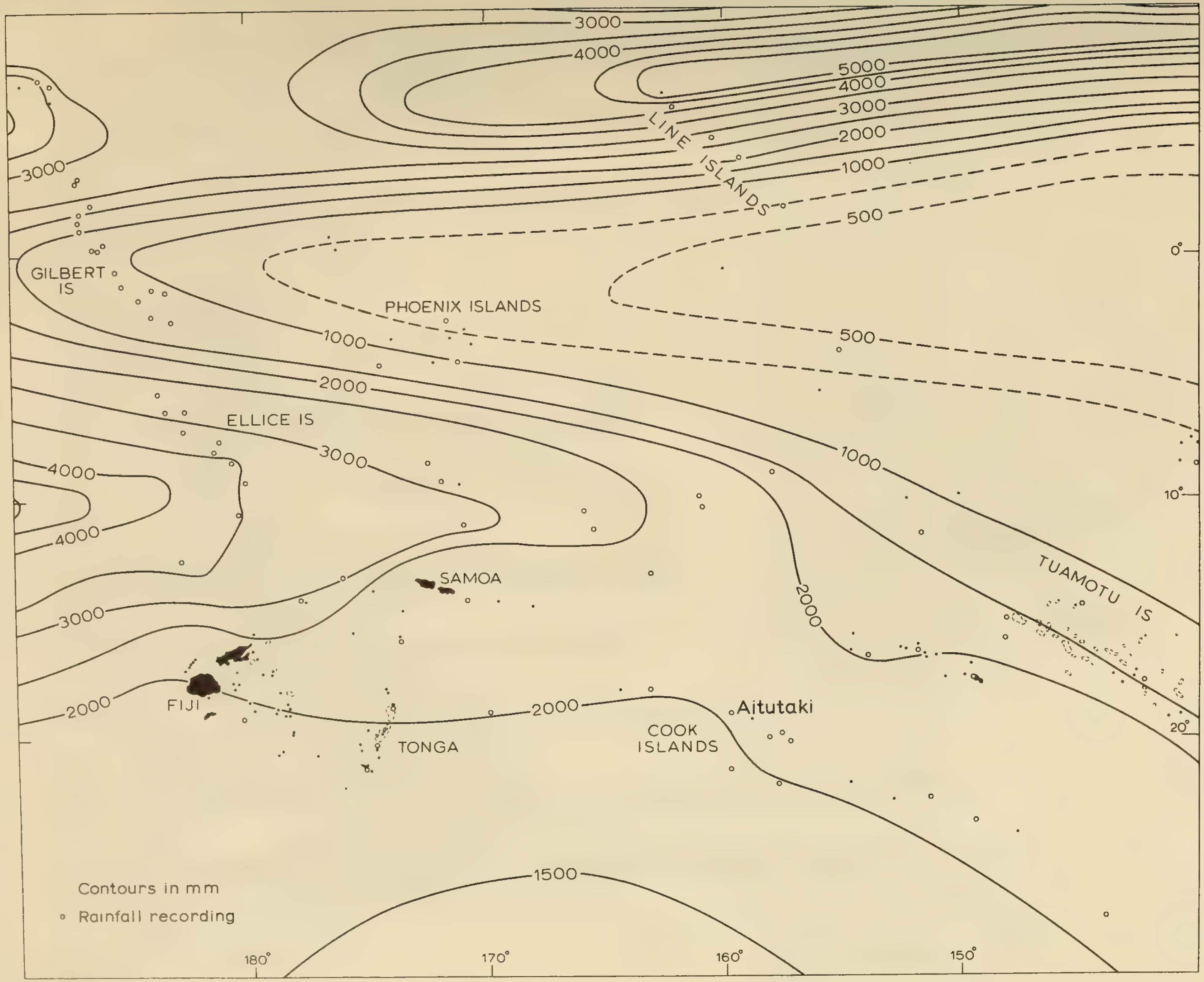

Figure 4. Rainfall distribution in the central Pacific, based on Taylor (1973)

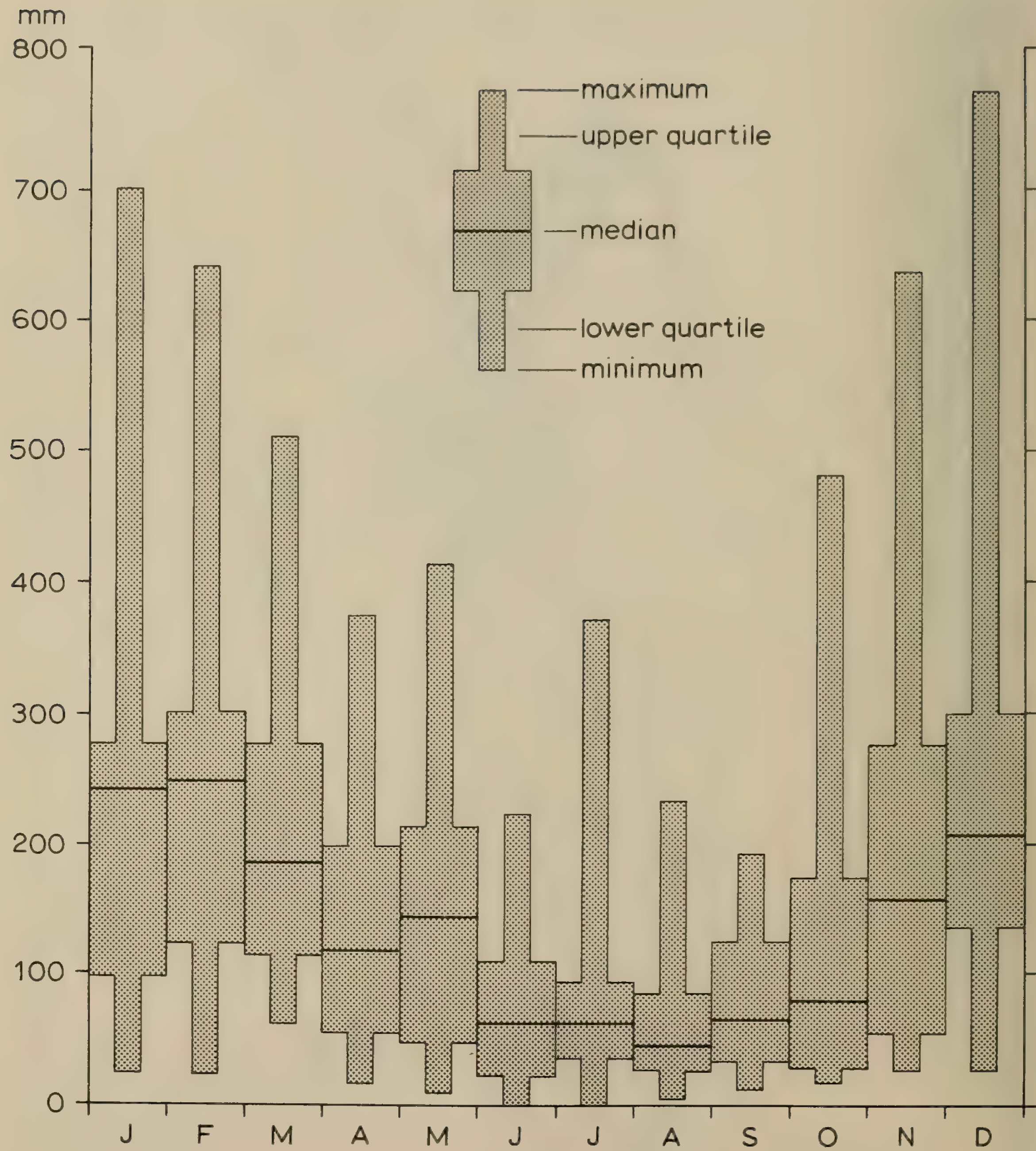

Figure 5. Monthly distribution of rainfall at Aitutaki, after Johnston (1967)

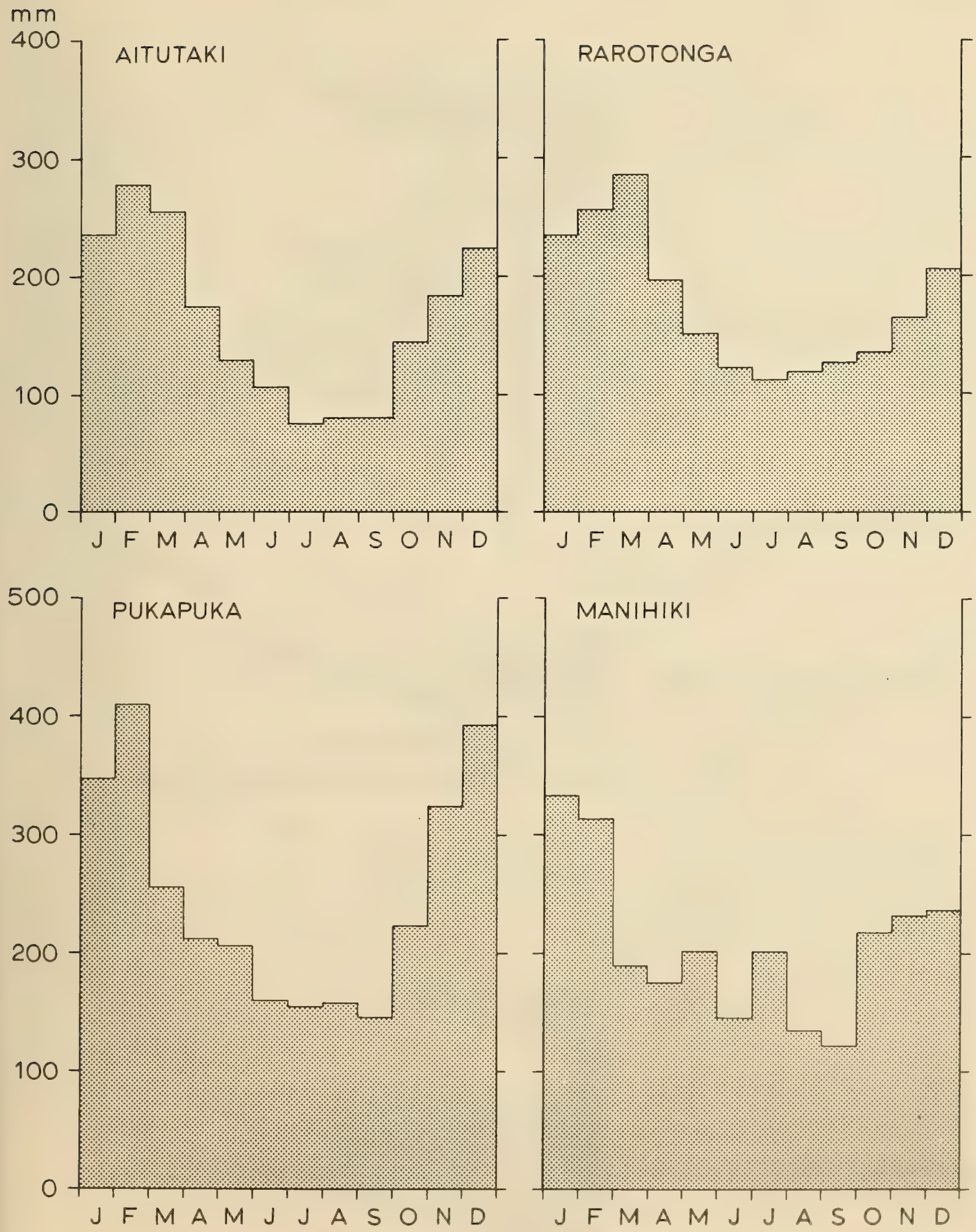

Figure 6. Monthly distribution of rainfall at Aitutaki, Rarotonga, Pukapuka and Manihiki

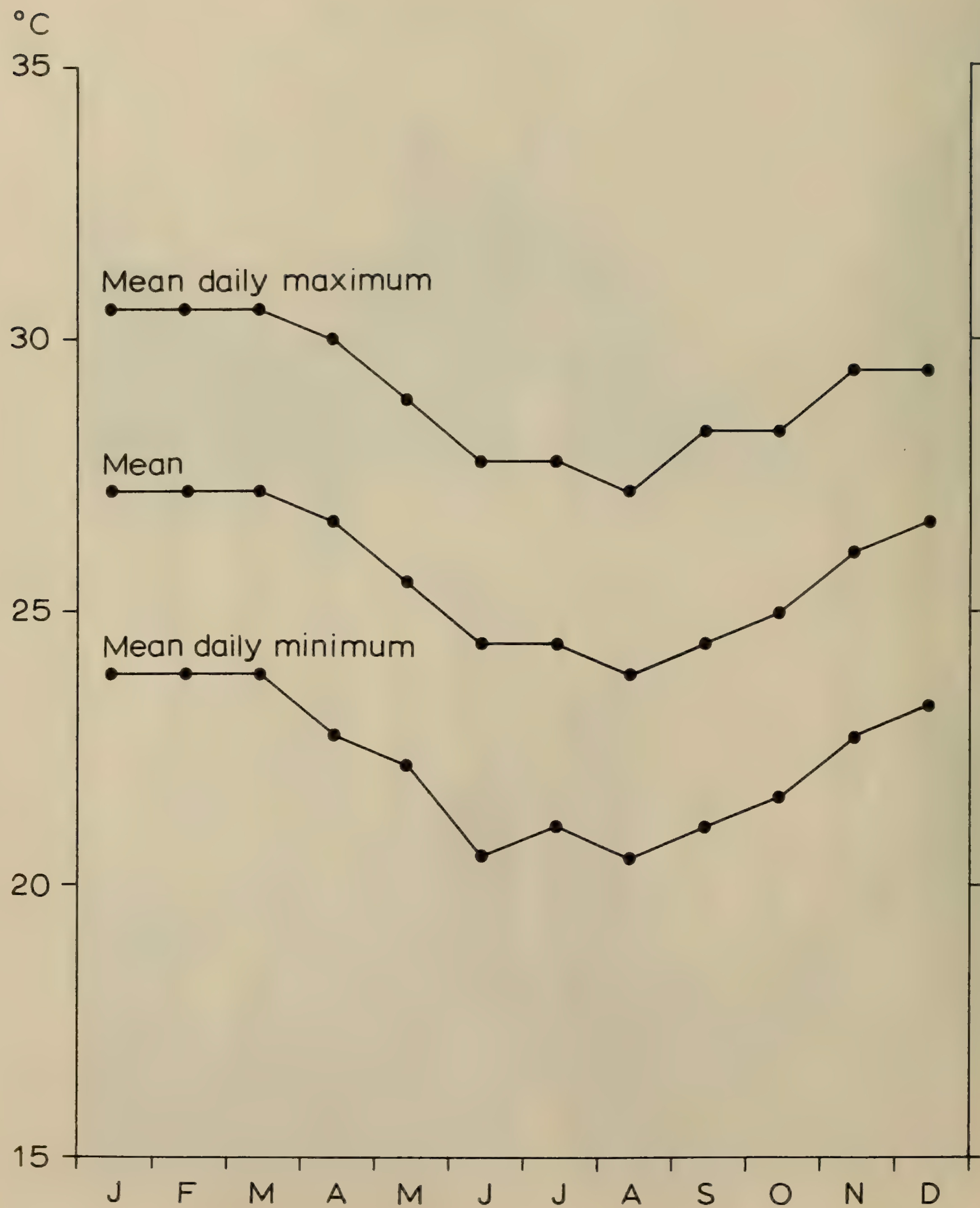

Figure 7. Monthly distribution of temperature at Aitutaki, after Johnston (1967)

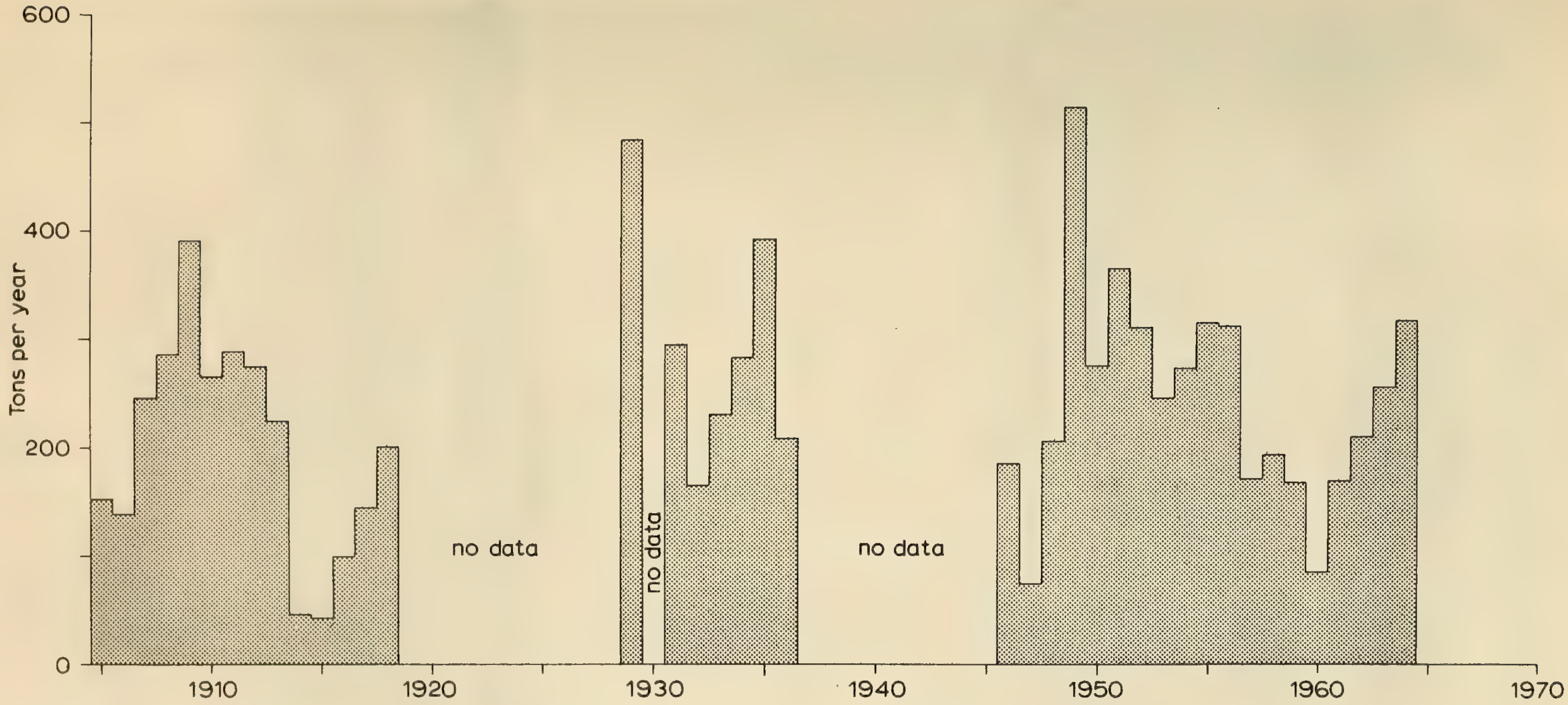

Figure 8. Copra exports from Aitutaki, after Johnston (1967).
Date to 1964 only.

1 Aitutaki in the nineteenth century (Gill, 1855, p.202)

2 Aitutaki in the nineteenth century (Gill, 1872, p.6)

2. ALMOST-ATOLL OF AITUTAKI: GEOMORPHOLOGY OF REEFS AND ISLANDS

D.R. Stoddart

"ALMOST-ATOLL": TERMINOLOGY

Charles Darwin (1837, 1842), in his initial classification of reefs, distinguished three types--fringing, barrier and atoll reefs--which he arranged in a developmental sequence controlled by subsidence of the reef foundations and concurrent upgrowth of the reef itself. The characteristics of fringing and barrier reefs were not rigorously defined, and later workers, notably Davis (1928) and Tayama (1952), introduced both intermediate terms and end-members in Darwin's sequence (Steers and Stoddart, 1974).

The term "almost-atoll" was introduced by Davis (1920; 1928, p. 7) for situations where "the lagoons of certain barrier reefs are so little occupied by islands that their reefs almost become atolls. Reefs of this kind will be called almost-atolls." No precise limits were set on the size of the volcanic residual in relation to the peripheral reef in so defining the term. Tayama (1952, p. 221) used the term in Davis's sense for "an intermediate type of [i.e. between] barrier reef and atoll. There is a central island as in the barrier reef, but it is much smaller than the lagoon". He later stated that "the area of the central island is extremely small when compared to the area occupied by the lagoon" (1952, p. 241). Both Davis and Tayama cite Truk in the Carolines as an example. Davis (1928, pp. 375-382), in the only systematic treatment of almost-atolls, also included Mangareva, Clipperton, Aitutaki, and several reefs near Fiji and New Guinea as examples; all meet Tayama's size criterion. By implication reef-encircled high islands such as Ponape and Bora-Bora should be classed as barrier-reef islands rather than almost-atolls.

Two points must be made about this nomenclature. First, the genetic implications of "almost-atoll" are considerably stronger than for the now more neutral descriptive terms of barrier reef and atoll. Davis (1920) laid great stress on the shoreline characteristics (presence of embayments, absence of cliffing) of the residual islets of almost-atolls, and inferred that rates of subsidence are greater than the rate of subaerial degradation of such islets. As Sachet (1962, p. 3) notes, however, a wide variety of islands have been included in the class of almost-atolls, and they "may have nothing in common beyond the fact that they include both coral and volcanic features."

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It seems useful to retain the term, however, defined descriptively in Tayama's sense, while noting that in some cases (though probably few) the mode of origin of the features may not be that proposed by the originators of the term.

Second, however, unnecessary confusion has been introduced by the use of the term with a different meaning and by the introduction of redundant new terms for the forms covered by the original definition of almost-atoll. The confusion is made worse by the fact that some of these new terms have previously been used in the literature with a different meaning.

Wiens (1962, p. 100) uses the term almost-atoll for volcanoes which have subsided so rapidly that their reefs were drowned, or which were submerged without corals being established on them. He apparently broadens the term to include guyots. Almost-atoll is thus used for features which almost became, or had the potential to become, atolls, but failed to do so. Genetic terminology such as this is always dangerous, and descriptive terms already exist for the features referred to.

A redundant synonym for almost-atoll is the term "near-atoll" introduced by Stearns (1946, p. 251) and adopted for Aitutaki by Wood and Hay (1970, p. 36). This has no advantage over the earlier term, and has the disadvantage that it has been applied to atolls parts of the rim of which do not carry surface reefs. Fairbridge (1950, p. 345) used it for incompletely closed annular reefs, and MacNeil (1954, pp. 395-396) for atolls with "very large reefless segments," when "their foundations are closed figures capable of supporting reef across the unfilled gap, whereas if the platforms are curved or U-shaped and the reef covers their top completely, they should be called table reefs." MacNeil complicated the matter, moreover, by using "semiatoll" synonymously with near-atoll (1954, p. 395) although Fairbridge (1950, p. 359) had already used "semi-atoll" <u>sensu</u> MacNeil's table reef. The term semi-atoll had been used by Agassiz as early as 1894 (p. 146) for curved, horseshoe-shaped and semi-circular reefs such as those of Campeche Bank. Features to which the term semi-atoll has been applied by Fairbridge had also been termed "pseudo atolls" by Agassiz (1898, 105), in the sense of atoll-shaped reefs which had not developed in the Darwinian manner. This is a particularly unfortunate term, for it has been used for reefs with the same plan-form as atolls but in shallow rather than oceanic waters (the "pseudo-atoll" of Molengraaff, 1930, p. 56, equivalent to the "bank atoll" of Davis, 1928, p. 19, and the "shelf atoll" of Fairbridge, 1950, p. 342), for annular features superficially resembling atolls but lacking coral reefs (the "pseudatoll" of Verrill, 1900, p. 313, and "pseudoatoll" of Newell and Rigby, 1957, pp. 25, 45), and even as a synonym for micro-atoll (the "pseudoatoll" of Mergner, 1971, p. 154). This leads, however, to even more confused aspects of terminology.

We conclude that "almost-atoll" should be retained as a descriptive term as defined by Davis and Tayama, and that the use of "near-atoll" as a synonym be abandoned. The value of terms such as "semi-atoll" and "pseudo-atoll" needs close examination and more rigorous definition before being generally accepted. It is in Davis's and Tayama's sense that this paper examines the geomorphology of the almost-atoll of Aitutaki. Of all the almost-atolls listed by Davis in 1928 only Clipperton has recently been studied in detail (Sachet, 1962a, 1962b, 1962c), though there the volcanic residual is a minute pinnacle compared with that at Aitutaki. Comparison is probably more appropriate in the case of Aitutaki with atolls recently studied in the Tuamotu Archipelago (Mururoa: Chevalier _et al_., 1969; Raroia: Newell, 1956; Rangiroa: Stoddart, 1969) and the Society Islands (Mopelia: Guilcher _et al_., 1969), and with the barrier-island of Bora-Bora (Guilcher _et al_., 1969).

REEFS

Morphology

The gross features of Aitutaki have been described in the previous chapter. The detailed bathymetric mapping by Summerhayes and Kibblewhite (1966) shows that the island consists of a roughly circular cone rising from depths of more than 4 km, and capped by a triangular reef with low volcanic islands (Figures 9 and 10). Aitutaki lies at the northwestern end of a line of similar cones which includes the limestone-capped volcanoes of Mauke, Mitiaro and Atiu, the sea-level atoll of Manuae, and the submerged Eclipse Seamount rising to -1.75 km. The highest point on the main volcanic island of Aitutaki reaches 119 m; two small volcanic islands are located near the southern reef of the almost-atoll, but all the other small islets are of clastic reef material. Volcanic rocks underlie the eastern reefs at shallow depth (Hochstein, 1967).

Bathymetric data indicate that reef slopes outside the reef edge are steep along the south side of the almost-atoll, intermediate on the west side, and more gentle on the east where the 250 m isobath is located 1-3 km from the reef edge (giving a mean angle of 5-14°). The only sector of the reef to have been surveyed in detail (by H.M.N.Z.S. _Lachlan_ in 1961) is that off Arutanga on the northwest coast (Figure 11). This shows a fairly well marked shelf or terrace at a depth of 10-20 m, extending outwards for about 200 m from the reef edge, with a marked steepening to seaward. This may be the equivalent of the "ten fathom terrace" described from the Marshall Islands by Emery _et al_. (1954) and from other Pacific areas including the Tuamotus (Newell, 1956, pp. 334-335). It is not known whether it is a common feature round the atoll. Groove and spur topography is not conspicuous on the upper seaward slopes of the reefs.

The sides of the triangle formed by the Aitutaki reefs are 13-15 km long, and the total length of the peripheral reefs is 45 km. The reefs are mostly 600-1000 m wide, with a maximum of 1700 m. This compares with mean and maximum widths at Mopelia of 1000 and 1500 m and at Bora-Bora of 1500 and 2000 m. Tuamotu reefs are also comparatively narrow in spite of the great size of many of the atolls: widths at Raroia range from 500-700 to 800-1250 m and at Rangiroa from 320-650 to 750-1100 m. The triangular form of the Aitutaki reefs must reflect patterns in the volcanic basement; Wood and Hay (1970) suggest that minor irregularities and re-entrants in the surface reefs may result from slumping and collapse of reef limestones. There are no deep passes or channels through the peripheral reefs, a situation in common with that of atolls in the northern Cooks, and water exchange between lagoon and ocean is hence entirely over the peripheral reef flats, and consequently mainly from the east at high tide.

Zonation

The reefs differ markedly in character on different sides of the almost-atoll, as would be expected in a trade wind location. Representative transects have been described by Stoddart and Pillai (1973) and fuller details are given by Pillai and Stoddart (*in litt.*); we here summarise features of geomorphic significance.

The eastern (windward) reef is continuous and forms a rock flat 0.6-1 km wide, much of the surface of which is occupied by detrital reef islands. The level of the flat is higher opposite islands and lower between them, where scouring may occur. Conversely the flat is generally narrower where occupied by islands and wider where not, because of the development of submarine sand deltas between islands on the lagoon slope. The lagoon reef edge is thus lobate in plan in contrast to the straighter seaward edge. Though little of the reef flat dries at low water, it is not an area of active reef construction. Corals grow in rock-floored moats near the seaward margin of the flat, and in deeper, more sheltered areas between islands, but they grow on planed rock surfaces and are not genetically related to the reef limestone on which they stand. A typical transect (Plate 3) at Kopuaono, Ootu, shows the following main physiographic zones:

(a) algal rim, 40 m wide, standing 0.6 m above the general level of the reef flat and emersed by up to 15 cm at low water spring tides (Plates 4-5). The rim is deeply dissected by surge channels at least 2 m deep at their heads. It is coated with crustose *Porolithon*, a turf of filamentous algae, and larger algae such as *Sargassum* and *Turbinaria*. Corals are limited to encrustations on the seaward side of the rim and small colonies on the sides of surge channels. They are mainly species of *Acropora* and *Pocillopora* and the hydrozoan *Millepora*.

(b) zone of green algae on the inner part of the algal rim, 5-10 m wide.

(c) inner slope of the algal rim, 15 m wide, covered with encrusting pink algae and *Turbinaria*, and with a smooth surface.

(d) moat, 75-85 m wide, 0.3-0.5 m deep at low water spring tides and 1 m deep at high springs. The moat has an eroded and hummocky rock floor, with little sand and gravel, and with scattered colonies and patches of coral, including large microatolls of *Porites lutea*.

(e) narrow rippled sand zone at the inner edge of the moat, 5 m wide, passing to the island beach.

The western reefs are 0.8-1.7 km wide and in the north abut against the main volcanic island. The reef flat is deeper in this northern sector than on the eastern reefs. Well-defined surge channels are absent, or are broad and irregular features. Wood and Hay (1970, 39) have suggested that irregularities in the reef edge result from localised slumping. The flat increases in depth from the land towards the sea where a narrow constructional barrier of corals rises from depths of 3-4 m. In the south the wide and rather deep reef flat is absent, and the reef is formed by coalescing coral colonies with sinuous intersecting channels between, rising from a general level of 3-4 m. In the north a typical transect at Vaioue, where the flat is 900 m wide, shows the following zones:

(a) reef edge, irregularly dentate with surge channels without an algal ridge, formed by coalescing coral colonies and rubble forming an openwork structure superficially bound with pink encrusting algae. Conspicuous organisms include encrusting *Acropora*, soft corals and *Turbinaria*.

(b) outer flat, coral colonies, mostly ramose *Acropora*, with deep winding channels 2 m deep between.

(c) main reef flat, 500 m wide, a sandy surface with coalescing and anastomosing linear coral patches, dead on their upper surfaces and rimmed with *Millepora* but with living corals on their sides.

(d) an inner zone, 50-100 m wide, of mainly dead corals, including living microatolls 1-2 m in diameter of *Porites lutea*, covered with bushy *Turbinaria* on their upper surfaces.

(e) mainland beach.

Devaney and Randall (1973) examined the seaward slope of the western reefs in the south, from depths of 3 to 35 m. They found that 80-90 per cent of the corals on the slope were dead, and considered it "very possible" that this resulted from an *Acanthaster* infestation, though no starfish were seen.

Reef blocks are common on and near the reef edge in the north (Plate 6). They are up to 2 m in diameter and consist of single coral colonies or more often fragments of reef limestone detached from the reef. Coral colonies in the blocks are often inverted and there is no doubt of the storm origin of these features. There is a further cluster of blocks near the southwest point. Black Rock, midway along the west reef, is a mass of storm-tossed coral conglomerate 15 m long and 3 m high, located about 50 m back from the reef edge.

The southern reefs average 0.8 km in width; there is no algal rim. Much of the width of the reef flat consists of a sand flat 1-3 m deep, with constructional reef corals forming an open framework interrupted by pools (Plate 7). These reef patches coalesce and become more continuous towards the seaward edge. The reefs are protected from both the Trades and presumably also hurricane waves; there are no large storm blocks and much delicate coral growth. Tridacna maxima is very abundant on these reefs, modifying coral growth forms, weakening limestone structures, and forming the basis of a major local food-gathering industry (Gill, 1885, p. 153).

LAGOON

Morphology

The lagoon of Aitutaki forms a triangle interrupted in the north by the main volcanic island, with arms of the lagoon extending northwards to east and west of it. The total area of the lagoon is 50 sq km.

Early charts (e.g. Army Map Service 1:50,000, 1942) showed depths of $3\frac{1}{2}$-$4\frac{1}{2}$ fathoms (6.4-8.2 m) in the western part of the lagoon, 2-3 fathoms (3.7-5.5 m) in the northeast, and 2-4 fathoms (3.7-7.3 m) in the southeast. A maximum depth of 6 fathoms (11 m) was recorded close inshore at Akaiami. During the Eclipse Expedition Summerhayes (1971) prepared a first bathymetric map of the lagoon based on 48 wire-line soundings fixed by prismatic compass; this shows a trough along the eastern half of the lagoon with depths greater than 20 feet (6.1 m) and a maximum depth of 36 feet (11 m). In the southwest of the lagoon the floor slopes inwards from the reefs towards the main island, with maximum depths of ca 20 feet (6.1 m).

In 1969 a bathymetric survey was carried out using a Marconi Offshore 500 echosounder. 86.5 km of echotraverses were completed, together with 108 line soundings; positions were fixed by horizontal sextant angles mainly on the eastern reef islands mapped from air photographs. The location of the traverses and soundings is shown in Figure 12 and the resulting bathymetric chart in Figure 13. The lagoon comprises two separate basins each more than 6 m deep. The deepest part of the

lagoon is found in narrow channels, visible on air photographs, between reef patches in the northeastern arm, between the main island and Mangers, where depths of up to 10.5 m are found. These depressions have the appearance of arcuate scourholes rather than karst sinkholes, but comment on their origin must at present be speculative. The greater part of the lagoon is considerably shallower: 75 per cent is less than 4.5 m deep. We did not locate the areas of deeper lagoon (greater than 9 m) west of Akaiami reported by previous surveys.

On its eastern side the lagoon terminates abruptly against the steep wall of the eastern reef, which is rapidly aggrading as fresh sediment is swept across the reef-flat to form inter-island lobes on the lagoon margin. The foreslopes of these lobes are the steepest parts of the lagoon slope. The main island is surrounded by a platform 0.75-1 km in width, which dries for about half its width at low spring tides; the outer slopes of this platform are also steep. Elsewhere, on the south and west sides of the lagoon, the marginal slopes are much less clearly defined, being formed by an iregular and intricate coral framework with little sediment accumulation and no continuous lagoon slope.

The Aitutaki lagoon is thus exceptionally shallow, both by comparison with lagoons of atolls as a class and with those of atolls in the central and eastern Pacific. Thus in the northern Cooks, maximum lagoon depths are 64 m at Manihiki, 66 m at Penrhyn and 80 m at Suwarrow (Wood and Hay, 1970), and in the Tuamotus 55 m at Raroia and 63 m at Rangiroa; all of these are large atolls. But Mopelia, with a lagoon approximately half as large (26 sq km) as that of Aitutaki, has a maximum depth of 40 m, and the same maximum depth is found in the lagoon of Bora-Bora (Guilcher _et al_., 1969).

Two factors could help to account for lagoon shallowness at Aitutaki: infilling with sediment, and reef growth. There are no deep channels through the peripheral reefs of Aitutaki, and hence export of sediment from the lagoon must be small. 38 linear km of peripheral reef are supplying sediment to the lagoon, a ratio of 1 km of reef to 1.3 sq km of lagoon. This compares with 1:2.5 at Eniwetok, 1:2.6 at Raroia, 1:6.0 at Bikini, 1:6.8 at Rongelap, and 1:6.8 at Rangiroa. The inferred relatively rapid filling of the lagoon by sediment at Aitutaki is probably increased by the frequency of hurricanes capable of transporting sediment lagoonward. The presence of a volcanic island on the margin of the lagoon, although shedding sediment, is not thought to be a significant factor in lagoon filling.

The role of reef growth is difficult to assess. Small reef patches are abundant in the southwest and south of the lagoon, though less common in the northeast and extreme south-east. It is unusual for there to be so many small patch reefs in a lagoon with no deep entrances and presumed high rates of

sedimentation, and also surprising that although so abundant the patches have in general not coalesced to form substantial constructional features. At several points around the lagoon margins, particularly near Maina and along the east rim, the patches are being buried by marginal sediments. Many of the patch reefs close to the main island, particularly in the turbid water of the northeast arm, are dead. These were formerly covered with Lobophyllia communities and it is possible that death resulted from predation by Acanthaster. Devaney and Randall (1973) found up to 90 per cent of branching corals dead on patch reefs in the northwestern arm, and ascribed this to an advancing front of Acanthaster, though only small numbers of starfish were seen.

Large surface reefs are not common in the lagoon, except in the southeast, where Summerhayes (1971) has already drawn attention to the irregular ridges, visible on air photographs, extending from the main island towards Maina. These are flat-topped, steep-sided ridges with abundant coral growth on their sides; because of their continuity across the lagoon they make navigation from east to west difficult. Summerhayes (1971, p. 359) on the evidence of their pattern suggests that these ridges are coral reefs which began growing on the gravels of dendritic streams which drained the highlands during glacial low sea levels.

Sediments

One hundred and fourteen sediment samples were taken in the lagoon during the 1969 Expedition; of these 20 were dredge samples and the rest grab samples (Figures 14-15). In addition, 93 sediment samples were taken on transects normal to the shore of the main island to determine trends in the distribution of non-calcareous constituents. Results of the sediment work will not be presented here, though Gibbs considers the infauna of the lagoon floor later in this Bulletin. Three main facies can be distinguished: (1) mixed terrigenous-calcareous poorly sorted sands from the shallow shelf around the main island; (2) moderate to well-sorted medium to coarse sands of the reef flats and reef islands; (3) generally poorly sorted fine silty calcareous sands with areas of coarser sands on the lagoon floor. The lagoon floor sediments are highly variable because of the abundance of reef patches.

At Aitutaki, as elsewhere (e.g. Bora-Bora, Mayotte, New Georgia), the terrigenous component is localized near the volcanic island, and the lagoon floor deposits are almost entirely calcareous. Insoluble residues are low even on the beaches of the main island, in spite of Agassiz's (1903, p. 170) statement that these sands are mainly volcanic. As in other lagoons lacking deep passes, e.g. Diego Garcia, patches of fine sediment are found in enclosed basins even at shallow depth. Detailed analyses of the sediments and their distribution patterns will be reported elsewhere.

REEF ISLANDS

Morphology

There are two types of reef island on Aitutaki: motus and sand cays. "Motu" was introduced as a technical term by Newell (1961, pp. 102-3; also Danielsson, 1954, p. 94) for atoll islands, especially those of Tuamotuan atolls. He initially used the term synonymously for sand and gravel cays, but since there is a considerable difference in form and origin between islands of the Tuamotu type and simple sand cays, it is appropriate to differentiate the two types by the use of the terms motu and cay (Stoddart and Steers, 1974).

Motus are restricted to the eastern reef rim, where there are twelve separate islands, from Akitua in the north to Motukitiu in the south. The Ootu peninsula in the north, though adjoining the main island, can in many respects be considered as simply the longest and largest of the motus (it is 3 km long, with an area of about 175 ha), though its morphology has been obscured by airstrip construction. The other islands are generally of similar width, transverse to the reef edge (300-400 m), but vary in length from 150 to 2250 m. The ratio of longest to shortest dimension, as an index of shape, varies from 1.2 to 4.7, the larger islands (Ee, Akaiami, Tekopua) being more elongate. Table 6 gives dimensions of these islands and of the sand cay of Maina on the southwest reefs. The islands, together with the two small volcanic islets of Moturakau and Rapota, are described in the following chapter.

Similar restriction of islands to the eastern (windward) reef is found on Mopelia and Bora-Bora in the Society Islands (Guilcher *et al*., 1969), but it is not characteristic of atolls in the northern Cooks (Wood and Hay, 1970), nor is it well-marked among the atolls of the Tuamotus.

In a transect from the reef edge to lagoon shore, the following zones may be recognised on a typical motu at Aitutaki (Figure 16):

(a) reef edge with raised algal rim, 30-95 m wide.

(b) rock-floored moat, with a discontinuous carpet of sand and gravel and scattered coral communities; the moat is generally less than 1.5 m deep and is 70-150 m wide.

(c) conglomerate platform, up to 0.5 m above high water level, up to 95 m wide but averaging 50 m.

(d) sheets of rubble, gravel and sand forming the seaward sides of the motus, with occasional large boulders; this zone is usually 100-150 m wide and covered with a scrub of *Pemphis* and *Suriana*.

Table 6. Dimensions of Aitutaki islands

Island	Width of reef rim	Width of moat	Total width of seaward reef flat	Maximum length of island	Maximum width of island	Width of conglomerate platform	Width of gravel spread	Area
	m	m	m	m	m	m	m	ha
Akitua	50	150	200	750	310	50	100	14.86
Angarei	65	90	155	480	400	40	187	13.07
Ee	50-85	130	170-210	975	410	50	50-430	29.21
Mangere	65	90	150	400	280	35-55	160	8.54
Papau	65	100	160	400	200	35-75	75	5.26
Tavaerua Iti	95	55	150	250	210	55	85	4.12
Tavaerua	65	70	120-150	500	290	55	130	12.47
Akaiami	35-90	125-150	190-250	1120	410	30-65	-	41.91
Muritapua	45	150	195	360	150	95	125	4.04
Tekopua	30-80	140	150-220	2250	480	65	-	71.29
Tapuaeta	-	-	-	570	210	-	-	5.96
Sand cay	-	-	-	175	75	-	-	0.95
Motukitiu	-	-	-	450	300	-	135	11.47
Moturakau	-	-	-	460	120	-	-	3.86
Maina	-	-	-	710	310	-	-	16.96

Rapota (no data).

(e) leeward sand area, the highest part of the motu, with a woodland vegetation.

(f) sand beaches and sand spits on the lagoon shore.

Two motus depart from this pattern. Akaiami and Tekopua, the largest islands, both have well-marked seaward beach ridges immediately overlying and in places obscuring the conglomerate platform: the wide rubble and gravel sheets are absent. The Ootu peninsula has a similar structure. These differences in morphology are reflected in the vegetation pattern on these islands.

Conglomerate platform

The conglomerate platform (Plates 8-14) consists of coarse and poorly sorted reef debris, mainly coral and molluscan shell material, tightly cemented in a sandy matrix. The upper surface of the platform lies up to 0.5 m above high water mark, but is constantly wetted by spray; depressions on its surface carry standing water. The horizontal surface is black in colour and rough-textured, except where wave action has recently detached blocks of material from it, when the scars are white. At lower levels the surface becomes yellow and then white, and also becomes smoother. The edges of the platform are vertical or undercut, and waves break against them with some force on a rising tide. In plan the edge of the platform is usually very irregular, with promontories and long straight or angular channels extending back towards the island. Sectors of the platform may become detached by these channels to form separate outcrops. Mostly these are small, but in some cases, as between Akaiami and Muritapua, there are substantial isolated areas of platform with no island sediments and either unvegetated or with a few *Pemphis* bushes. These remnants suggest that the platform was formerly more extensive, and that some islands, notably Angarei, Ee and Mangere, were formerly continuous. The conglomerate platform does not outcrop on the lagoon shores of islands, and only extends lagoonward along the sides of inter-island channels for 50-100 m.

Very similar conglomerate platforms were described at Raroia in the Tuamotus by Newell (1956). These platforms (*pakokota*), rising to 0.5-1 m above mean high water, are found on the seaward shores of islands both on the windward and the leeward sides of the atoll. Newell's diagrams (1956, figures 6B, 6C, 6E and 7A) show features directly comparable to those of the Aitutaki motus, i.e. wide seaward conglomerate platforms, extensive seaward rubble and gravel sheets, and a dry-land area of sediments on the lagoon side. Such situations are, however, less common at Raroia than cases where a narrow conglomerate platform is overtopped by a high seaward beach ridge, as at Tekopua, Akaiami and Ootu on Aitutaki. Seaward beach ridges are also more common on Rangiroa than are gravel sheets

(Stoddart, 1969). A second point of difference between Aitutaki and the Tuamotus is that in the latter the conglomerate platform is of much greater lateral extent on the reef flats than the motus themselves (Newell, 1956, pl. 32-34), while on Aitutaki the areas of platform are more closely related to the size and location of the motus. At Rangiroa also the platforms, though less well developed on their seaward sides, are extensive _between_ islands (Stoddart, 1969, p. 9). A minor difference noted by Newell (1956, pp. 330-332) is that the Raroia platforms are unvegetated, whereas at Rangiroa and also at Aitutaki, while more exposed areas are bare, the inner sections support a scrub of _Pemphis_ and _Suriana_.

At Aitutaki the conglomerate is everywhere a clastic rock and not an elevated reef rock: it does not contain any reef corals in the position of growth but only broken and worn coral fragments and mollusc shells. The constituent material is poorly sorted and variable in size, and there are no structures suggesting submarine deposition. At Raroia, Newell (1956, p. 332) found that _pakokota_ is "clearly bioclastic throughout and does not contain _in situ_ reef material. It is not an elevated platform of planation, a reef flat, but it is a depositional surface ... [which] could have been formed at or near the existing sea level"; a similar conclusion was reached at Rangiroa (Stoddart, 1969, p. 22). Superficially similar conglomerate ledges on reef islands of Bora-Bora and Mopelia, Society Islands, however, have been found by Guilcher _et al_. (1969, pp. 26-28) to consist largely of reef corals in the position of growth overlain in places by conglomerate of the Aitutaki and Tuamotuan type; these ledges reach about 1 m above present sea level. Conglomerate platforms 10-200 m wide and 0.6-1.3 m above mean high water springs are also described from Mururoa (Chevalier _et al_. 1968, pp. 17-25); these too are bioclastic and have no _in situ_ reef material, but Chevalier quotes dates of 3000-4000 yr B.P. and interprets them in terms of a Holocene higher stand of the sea. Elsewhere he considers the _feo_ of Tuamotu atolls to be a dissected conglomerate platform (Chevalier, 1973, pp. 118-119). Conglomerate ledges have also been described from islands in the Carolines and Marshalls, west Pacific, and interpreted as clastic rocks, by Shepard _et al_. (1967) and Curray _et al_. (1970). These Micronesian platforms have flat upper surfaces standing at up to 1.2 m above the present reef flats, are submerged at high tide, and contain no growth-position corals.

An important constituent of the Aitutaki conglomerates are valves of the clam _Tridacna maxima_ Röding. Two samples were taken for carbon-14 dating: sample F-52 from the seaward platform at the south end of Akaiami, and sample F-56 from the platform on the seaward side of Muritapua; both valves were tightly cemented in the upper part of the conglomerate. The results were as follows:

Table 7. Conglomerate platform carbon-14 dates

Sample number	Elevation, m	Analysis number	Age
F-52	0.5	GaK-3496	2040±90
F-56	0.4	GaK-3500	160±80

Source: dating by Dr K. Kigoshi, Gakushuin University

These dates indicate the recency of the material composing the platforms and hence of the features themselves; they are compared with dates from similar features elsewhere in the Pacific in the following section.

Beachrock

Beachrock (Plates 15-16) is uncommon on Aitutaki, except on the sand cay of Maina, where rather weakly cemented single ledges of rock outcrop in the low intertidal on several sides of the island. The rock is sandy, with valves of *Tridacna maxima*. On the motus, there is a long line of older beachrock on the leeward shore of Tapuaeta, and in places beachrock caps the upper surface of the conglomerate platform. This is best seen on Tekopua, where there is a high seaward beach ridge: layers of seaward-dipping sandy beachrock are well exposed near the south end of the island. Similar cases of beachrock overlying conglomerate are reported by Guilcher *et al*. (1969) from Mopelia. Elsewhere some of the conglomerate outcrops themselves resemble beachrock (e.g. on Motukitiu), and it may be difficult to distinguish true beachrock from sandy conglomerate in such circumstances. Beachrock standing on the conglomerate is clearly younger than it. Two samples of modern beachrock from Maina, F-57 from the north shore and F-58 from the south, were dated by carbon-14:

Table 8. Beachrock carbon-14 dates

Sample number	Elevation	Analysis number	^{14}C	Age
F-57	Intertidal	GaK-3501	9.35±1.1%	modern; post-bomb?
F-58	Intertidal	GaK-3502	4.5±0.9%	modern

Source: dating by Dr K. Kogoshi, Gakushuin University

Rubble and gravel sheets and reef blocks

The wide areas of low-lying rubble and gravel on the seaward sides of most motus form the most distinctive and unusual features of the Aitutaki islands. The sediments are poorly sorted and very variable in composition, in places rubble, elsewhere coarse sand and gravel. In some areas, e.g. the unvegetated gravel sheets 100 m wide on Motukitiu, the material is fresh and white, but even where scrub-covered it is light-coloured and appears relatively recent. Thus coral heads in the rubble have not yet disintegrated through weathering. Reef blocks up to 1.5 m in height and 2 m in longest dimension are common (Plates 17-18), not only on the shore but also inland in the scrub on several islands, notably Ee, Papau and Muritapua. These consist both of single coral colonies and blocks of reef rock containing many smaller colonies. The reef blocks are loose boulders, uncemented at the base, generally still white in colour, and clearly storm-deposited. Both rubble and gravel sheets and the reef blocks are best simply interpreted as formed by hurricanes. It is possible that the storms responsible for these features on the northern islands (the Ee group) were different from those in the south (Motukitiu), and that the lateral extent of the effects of any single storm is limited. The implication is that where severe hurricane effects have not recently been felt, normal seaward beach ridges survive (at Ootu, Akaiami and Tekopua): this would explain the close juxtaposition of very different types of islands.

Island sediments

The sediments on the lee sides of the motus, under woodland, are mainly sand, with cobbles, gravel, and patches of rubble. Sandy beaches are frequently scattered with coral boulders and patches of rubble, and it is clear that normal processes of sediment accretion are interspersed with hurricane events. This is confirmed by two types of evidence. First, sections in the island sediments, as at Papau, show successive soil horizons buried by fresh layers of gravel and sand 10-20 cm thick, clearly derived from individual storm events. Similar evidence of storm accretion is recorded by Newell (1956, p. 337) in pits at Garumaoa, Raroia, where carbon-14 dates for the lower humic horizons range from 800 to 1730 yr B.P. Second, samples of *Tridacna maxima* from island sediments were taken at Muritapua for carbon-14 dating. Sample F-53 was from the seaward edge of the coconut woodland, approximately in the centre of the island. Sample F-54 was under *Pemphis* scrub near the northwest corner of the coconut woodland, close to the lagoon shore, elevation about 2 m. Sample F-55 was from an old beach ridge within the woodland, midway between the first two samples. The dates are as follows:

Table 9. Island sediment carbon-14 dates

Sample number	Analysis number	Age
F-53	GaK-3497	Modern
F-54	GaK-3498	100 ± 80
F-55	GaK-3499	470 ± 80

Source: dating by Dr K. Kigoshi, Gakushuin University

The conglomerate platform sample on this island gave a date of 160 ± 80 yr. Clearly the surface sediments and features of these islands are young, and storms are capable at the present time of depositing material not only on the shores but across the surface of the island. The approximate age-equivalence of the sediments and the conglomerate platform material is also interesting, suggesting that the platform is a contemporary feature related to present island sedimentation, rather than an inherited or fossil feature formed in the past.

Other island features

Other island features may be briefly noted. Beaches consist of well sorted sands and fine gravels of coral, algal and molluscan debris. In contrast to atolls in the Tuamotus, Foraminifera are an unimportant constituent. Beaches are narrow, except in sheltered crescentic bays such as those of leeward Akaiami and Tekopua, and many beaches are being eroded. This may be a seasonal phenomenon, but exposure of roots and apparent truncation of vegetation patterns suggests that it is more extensive in some areas. The main areas of aggradation on the islands are on sand spits at the northwest and southwest leeward points, especially on the larger islands, and at the leeward end of smaller islands such as Akitua and Tapuaeta. Calcareous sand tails are also found on the volcanic islets of Moturakau and Rapota. Some of these features may be followed into much wider submarine sand lobes aggrading on the lagoon reef slope. Sand dunes are curiously uncommon in such a trade wind location. Low dunes are found on the southern end of the Ootu peninsula, but not elsewhere. This contrasts with Tuamotuan atolls such as Rangiroa, where dunes up to 10 m high are found on the lagoon coasts of western reef islands (Stoddart, 1969, 14).

Channels between islands, especially between Mangere, Ee and Angarei, have many of the characteristics of Tuamotuan hoa (Chevalier, 1969; Stoddart, 1969). They appear to have been

formed by the dissection of previously more extensive land. Patches of island conglomerate extend across their seaward entrances, and they often deepen lagoonward by tidal scour.

Marsh areas are uncommon on the islands. There is one small area of Cladium marsh on Akitua, but otherwise no marshes or even internal depressions. Their absence presumably results from the importance of hurricane activity transporting sediments across island surfaces and the unimportance of marginal beach ridges. Attention may be called to the intertidal basins of silty sand in the northeastern arm of the lagoon, between the Ootu Peninsula and the mainland. These are unvegetated and occupied by meandering tidal channels. They resemble the barachois described from central Indian Ocean atolls, where, too, mangroves, which might otherwise colonise such situations, are absent (Stoddart, 1971). They are not, however, found on the reef islands.

SEA-LEVEL CHANGE AND THE AITUTAKI REEFS

In placing Aitutaki in the wider context of Pacific reef evolution, the following main points need to be considered: (1) the outer slope of the reefs is bevelled at 10 to 25 m depth; (2) the present reef flats are rocky abrasion surfaces, not growth features, at least on the windward side; (3) reef islands are being eroded on their seaward shores, exposing conglomerate platforms, and channels are being cut through some larger islands; (4) there is no unequivocal raised reef in the position of growth; (5) conglomerate platforms and beachrock yield recent dates, as do island sediments; (6) hurricanes are clearly important both as agents of deposition and erosion on the islands. This evidence suggests that the reef flats of Aitutaki are old features, pre-dating the present sea-stand and possibly last interglacial in origin, thinly veneered by modern reef growth, and that the islands are recent accumulations on them, formed mainly during and continually being changed by severe hurricanes. In a regional context the main problems of interpretation of the evolution of the Aitutaki forms are the local absence of makatea, the apparent absence of raised Holocene reefs, and the significance of the conglomerate platforms.

The Makatea problem

The southern Cook Islands are a classic location for makatea, elevated karst-eroded limestone caps encircling residual volcanic mountains on the islands of Mangaia, Atiu, Mauke and Mitiaro. On Mangaia the central volcanic island rises to 169 m and the makatea rim to 55-70 m; on Atiu the elevations respectively are 72 and 20-39 m; on Mauke 27.5 and 18 m; and on Mitiaro 9 m and 6-12 m (Marshall, 1927, 1930; Wood and Hey, 1970). Between the volcanic residual and the

makatea rim there is a swampy depression, and at one time there was much discussion over whether this represents an original lagoon, with the makatea rim an old barrier reef (Davis, 1928; Marshall, 1929), or whether it is a karst-erosional feature formed by run-off from the central hills (Chubb, 1927; Hoffmeister, 1930). It is now clear that the makatea limestones of the type-island, Mangaia, are of Miocene age and are largely non-reef in composition, and that the topography is not an original topography as Marshall and Davis supposed (Hoffmeister and Ladd, 1935; Wood and Hey, 1970, pp. 27-36).

On Rarotonga there is no ring of makatea; but a small outcrop of limestone is found on the north side of Ngatangiia Harbour, at Matavera, and on the islet of Motutapu (Stoddart, 1972). On Aitutaki there is no makatea at all. Aitutaki is separated from the makatea islands by the atoll of Manuae, but nevertheless the absence of evidence for positive movements on an island which could be as old as early Tertiary (Wood and Hey, 1970) is surprising.

Evidence is also reported from the makatea islands for the existence of erosional bevels on the volcanic rocks, and benches and notches on the limestones. These are said to be at similar altitudes on different islands in the southern Cooks, with equivalent benches and alluvial deposits on volcanic rocks of Rarotonga and Aitutaki, and to indicate Pleistocene high sea-level stands (Wood and Hey, 1970); Table 10 lists the main levels identified. Schofield (1959) found comparable levels at Niue, and, from the literature, claimed accordance with benches and notches on Eua, Tonga (Schofield, 1967) and in the Lau Islands, Fiji (Schofield, 1971). The analysis is carried further by Ward et al. (1971), who assume that the levels on Mangai are true eustatic levels, and use additional data from South Carolina and New South Wales to establish both a sequence and an absolute chronology for Pleistocene high sea levels. It should perhaps be stated that no satisfactory detailed field evidence of the extent, altitude and nature of the Mangaia features has ever been published, and the attempt to erect a Pleistocene chronology on this basis seems premature, if not bizarre. Further, the field evidence at Aitutaki does not, to me, satisfactorily indicate the existence of raised marine features, or, indeed, of any raised features of chronological significance at all.

In the interpretation of the modern reefs the lower shoreline features claimed in the Cooks are of greater importance. A shoreline at 1 m of Holocene age and a 2-3 m shoreline of last interglacial age are claimed for Aitutaki and Mangaia (Table 5). The Mangaia 2-3 m feature is based on uranium-series ages of 90,000±20,000 and 110,000±50,000 yr obtained by Veeh (1966, p. 3383) for samples at +2 m from a reef terrace up to 3-10 m high. This terrace is equivalent to raised reefs up to 5 m above low tide at Anaa and Niau Atolls in the Tuamotus

Table 10. Elevations (m) of raised platforms and notches in the Cook Islands

Mangaia	Mauke	Rarotonga	Aitutaki	Inferred Age
70			?76	Antepenultimate interglacial
52-55			?55	Penultimate interglacial
34-38			35	
23		21-23	18-21	
12-15	12	12	12	Last interglacial
5	4.6	6		
3			2-2.7	
1		1	1	?Holocene

Source: Wood and Hay, 1970, 76

(representative of the widespread feo of Tuamotuan atolls, present on Rangiroa though absent from Raroia), dated at between 110 ± 20 and $160 \pm 40 \times 10^3$ yr B.P. and with an 8 m reef terrace round Makatea Island from which a sample at 3 m yields dates of 100 ± 20 and $140 \pm 30 \times 10^3$ yr B.P. (Veeh, 1965, 1966). The outcrop of makatea on Rarotonga is probably of the same age as the Mangaian and Tuamotuan samples dated by Veeh: Schofield (1970) obtained a carbon-14 age of $28{,}200 \pm 850$ yr on this outcrop, but this, like the dates for similar raised reef at Te Ava Vaka, Rarotonga, of >43,400 quoted by Wood and Hay (1970) and >48,900 yr quoted by Schofield (1970), is probably too low: Thom (1973) has discussed the general difficulties of accepting carbon-14 dates in this age range. The Rarotonga limestone is similar to that of western Indian Ocean raised reefs assigned to the last interglacial by Veeh (1966), and similar dates have subsequently been obtained at other sites by Thomson and Walton (1972). There is, therefore, wide evidence, much of it from the southern Cooks and the Tuamotus, for a last interglacial stand of the sea at about +5 to +10 m above the present (cf. Lalou et al., 1971).

It would be surprising if there were not some evidence of this stand on present sea-level atolls in the central and east Pacific. Wood and Hay (1970, pp. 57-64) refer to low outcrops, often beneath recent conglomerates, of well-cemented dark "reef rock" on several atolls in the northern Cooks (such as Pukapuka, Penrhyn, Manihiki and Suwarrow), which may be of similar age. There is, however, no direct evidence for this stand at Aitutaki, other than in the planed-rock reef flats, which may be bevelling reef limestones of last interglacial age. There is no makatea, or feo, or similar deposits, above the present sea level.

Recent high sea levels?

Is there evidence at Aitutaki of higher sea levels since the last interglacial? Two types of evidence have been cited. First, Shepard (1961, p. 34) states that he "observed an elevated reef at two feet above sea level at Aitutaki" but that the outcrop was not dated. The location of this reef was not given. In 1969 the whole coastline of Aitutaki was traversed, both of the main island and of all the smaller islands, and no raised reef was found. Shepard must have interpreted the conglomerate platform as a raised reef, but, as has been described above, it is an entirely clastic rock. Second, Wood and Hay (1970, p. 39) refer to "beach deposits such as coral sand, partly cemented conglomerates, and lithified beach rock" which "form two levels 2-3 ft (1 m) and 7-9 ft (2-2.7 m) above high tide level around Aitutaki." The only deposits corresponding to the second of these levels are the low sand flats around the main island and the upper surfaces of the reef islands; the lower level presumably refers to the conglomerate platforms of the motus. Wood and Hay note that the "past sea levels represented by these deposits may have been little higher than at

present, and are almost certainly Holocene in age." In describing similar conglomerate benches on atolls in the northern Cooks they also comment: "They are not remains of a former higher sea level, and no conclusive evidence for a postglacial high sea level was found" (Wood and Hay, 1970, p. 56); this refers specifically to conglomerates on Pukapuka and Suwarrow Atolls.

It is clear that the nature and origin of the conglomerate platforms is central to any interpretation of the development of the present reefs and motus on islands such as Aitutaki. Comparable benches have been described in the southeast Pacific at Raroia (Newell, 1956), Rangiroa (Stoddart, 1969), Bora-Bora (Veeh, 1965; Guilcher et al., 1969), and Mopelia (Guilcher et al., 1969), as well as in the Cook Islands, and at many locations in the western Pacific (in the Carolines and Marshalls) and the north Pacific (in the leeward Hawaiian Islands).

At Mopelia, 600 km east of Aitutaki, and at Bora-Bora, the bench is described as partly a clastic conglomerate, and partly a raised reef in the position of growth. A sample of in situ reef material at +0.8 m on Mopelia is dated at 3450 ± 130 yr B.P., and a sample of conglomerate, possibly raised reef, at +0.8 to +1 m at Bora-Bora at 2250 ± 130 yr B.P. (Guilcher et al., 1969, p. 30). Morphologically the outcrops resemble those of Aitutaki.

Ten dates are available for samples from conglomerate ledges at up to +1.2 m at Truk, three atolls in the Carolines, and three in the Marshalls. The dates range from 1270 ± 95 to 4350 ± 110 yr B.P., but half cluster in the range 2500-3000 yr B.P. The ledges have flat upper surfaces, are submerged at high tide (and are hence lower than those in the Cooks and Tuamotus), and contain no corals in the position of growth. Like the Aitutaki platforms, they are interpreted as cemented rubble ramparts built during storms and subsequently eroded (Shepard et al., 1967; Curray et al., 1970). Curray et al. discuss the age-clustering of the dates. This could result either from a slight transgression or a change in the rate of transgression at about 3000 B.P., aiding sediment accumulation; or it could indicate a period of stormier conditions at about this time; or it could result from sampling bias. Further evidence for increased storminess in the period 3650 ± 125 to 4980 ± 150 yr B.P., though inferential, comes from the composition of rocks underlying the windward reef flat at Eniwetok Atoll (Buddemeier et al., in litt.). The older Aitutaki conglomerate platform date of 2040 ± 90 yr B.P. is consonant with this pattern of Pacific conglomerate dates.

Conversely, superficially similar rock ledges, forming platforms 2-10 m wide standing at 0.5-0.75 m above low tide, at Midway and Kure Atolls, have been interpreted as true reef rocks, not cemented rubble, by Gross et al. (1969); dates range from 1230 ± 250 to 2420 ± 300 yr B.P. Tracey (1968) quotes

carbon-14 dates on *in situ* corals at up to 1 m above present reef-flat levels from Guam, Midway, Bikini and Ifaluk of 1230±250 to 4050±300 yr B.P., mostly clustering in the range 2000-3000 yr B.P. Additional good evidence of a Recent relative high sea level comes from the Pacific equatorial islands, where Tracey (1972) has identified clear recent reef features at 1 m above present level on Enderbury (2150 and 2650 yr B.P.), Jarvis (1230, 1800, 1980 and 2800 yr B.P.), Starbuck (3950 yr B.P.) and Malden (3550 yr B.P. with a much older reefrock below). Finally, sequences of dates from northeast Brazil and from New Caledonia indicate at least local transgressions to +3 m at about 3500 yr B.P. and to +2 m at 2250 yr B.P. (Delibrias and Laborel, 1971; Coudray and Delibrias, 1972).

Some dates are also available within this range from Rarotonga. Schofield (1967a, 1970, 1971; Schofield and Suggate, 1971) describes beach deposits (Aroa Sands) up to 7.6 m above present sea level and overlying Pleistocene reef or *makatea*; modern beach ridges have a maximum elevation of 3.4 m above low tide. Aroa Sands samples yield dates as follows: +1.5 m, 3510±50 yr B.P.; 2.3 m, 2470 yr B.P.; 4.3 m, 1235±57 yr B.P. Schofield also notes a raised reef at Avarua, Rarotonga, at 1 m above low tide level, with a date of 2030±60 yr B.P., and interprets these data as indicating Holocene eustatic high stands of the sea.

There are thus substantial problems in the interpretation of reef and island features at Aitutaki. The *local* evidence indicates that the conglomerate platforms are storm rubble deposits which are continually accreting and eroding. A similar interpretation is reached for conglomerates in the Carolines and Marshalls by Curray *et al*. (1970). Newell (1956) also found the platforms at Raroia to consist of cemented rubble, though these do stand at a higher level than those of the west Pacific, and, according to Newell, indicate a slight regional uplift. The origins of such conglomerate platforms have been discussed by Newell (1961) and Newell and Bloom (1970), and their conclusions are similar to those reached at Aitutaki. But there is an increasing and impressive body of evidence in radiocarbon dates, many from central Pacific reefs, suggesting a slight transgression in the period 1000-4000 yr B.P. If this transgression was real, it would be helpful in explaining the presence of islands and platforms on the Aitutaki reefs, and might also explain the present state of shore erosion, island retreat and channel-cutting on reef islands, but at Aitutaki at least it is not a *necessary* component of the explanation.

CONCLUSION

From this survey of the main characteristics of the reefs and reef islands of Aitutaki it will be apparent that the distinctive characteristics of the geomorphology of this almost-

atoll arise almost entirely from its location in a hurricane belt, and that the fact that a volcanic island emerges through the reefs has remarkably little influence on either morphology or sediments of the surrounding area. The fact that Aitutaki is an almost-atoll rather than a true atoll is of little significance in an analysis of the present reef features.

Agassiz, who made the first field observations on the geomorphology of the Aitutaki reefs, completely misinterpreted them. Erroneously identifying storm blocks on the reef edge as "volcanic negroheads," he argued that:

> "This group is an excellent example of a volcanic rock flat upon which corals are growing. The formation of the underlying base can be traced, as volcanic outliers crop out at many places on the barrier reef. Aitutaki shows, perhaps as plainly as any other volcanic island we have visited, the manner in which the lagoon and barrier reef flats have been formed from the denudation and erosion of the volcanic mass which once occupied the area indicated by the outer edge of the barrier reef" (Agassiz, 1903, 170).

It is unnecessary to refute this argument, which Agassiz (1898) also proposed for features as large as the Great Barrier Reef of Australia, in any detail. Apart from Rapota and Moturakau, the volcanic outliers he refers to are all blackened storm-deposited reef blocks; the reef flats themselves are all of reef limestone and not abraded basalt; and the high cliffs which, as Davis (1928) forcibly argued, must have resulted from marine erosion on this scale, are absent from both the main island (there is only one small area of steep coast, near Teaitu) and from the volcanic islets.

All the evidence indicates that the almost-atoll of Aitutaki has developed by a process of subsidence and reef upgrowth as Darwin's theory indicates, and that the details of reef geomorphology here, as elsewhere, result from the effects of sea-level fluctuations in the Pleistocene and Recent, in the long term, and of repeated hurricanes in the short term.

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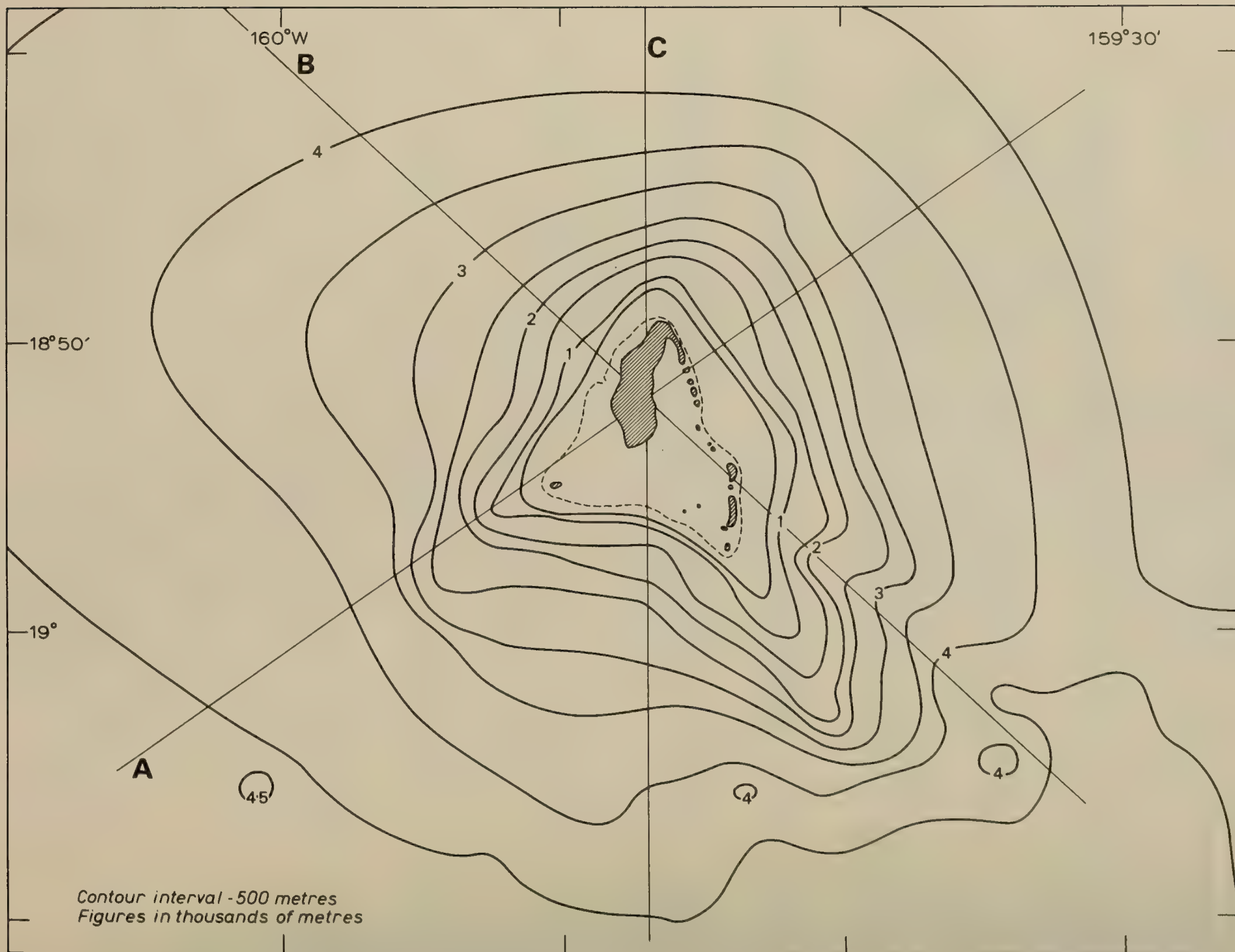


Figure 9. Regional bathymetry of Aitutaki, after Summerhayes and Kibblewhite (1966)

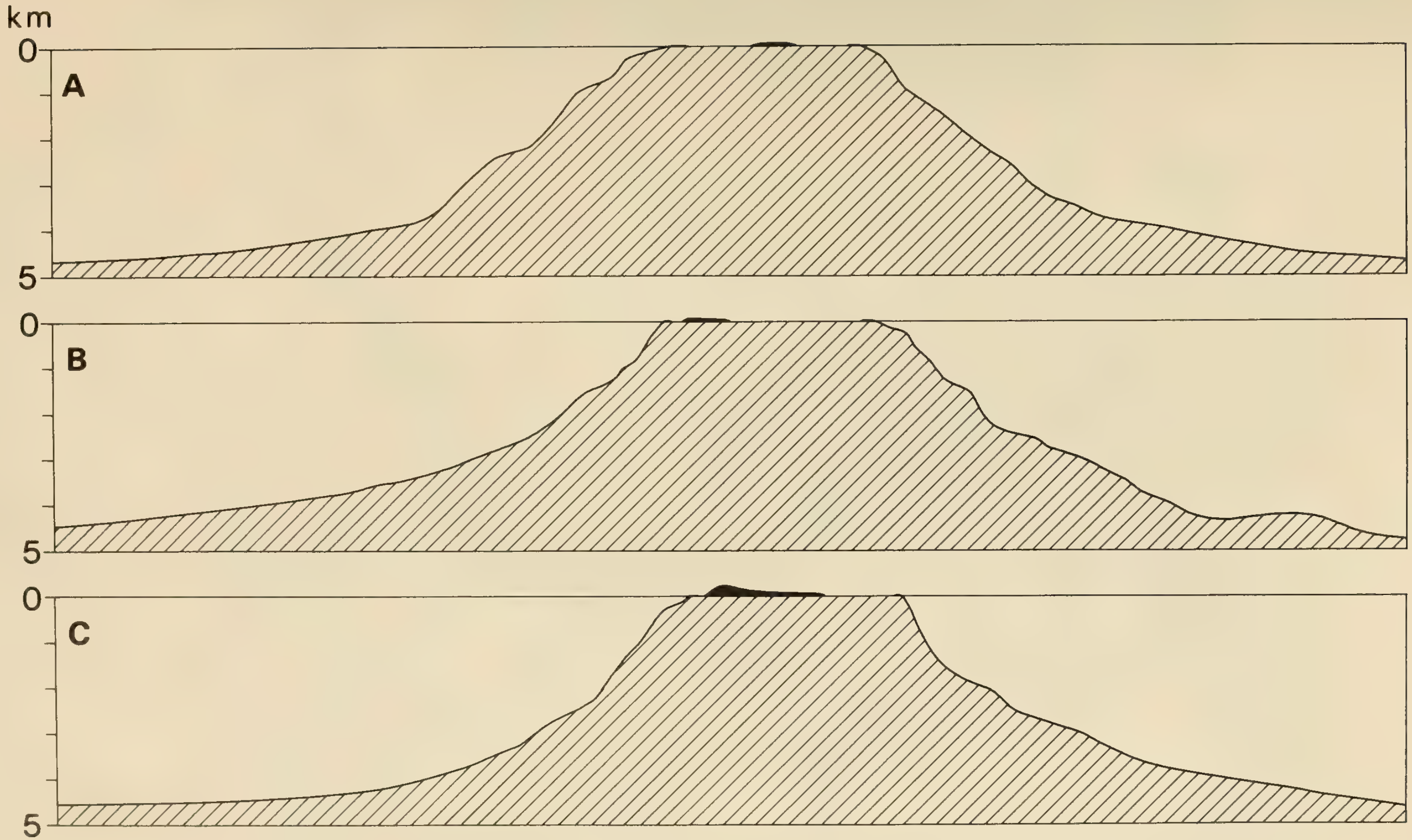


Figure 10. Bathymetric profiles of Aitutaki, from Summerhayes and Kibblewhite (1966)

Figure 11. Bathymetry of the reef near Arutanga, surveyed by H.M.N.Z.S. *Lachlan*

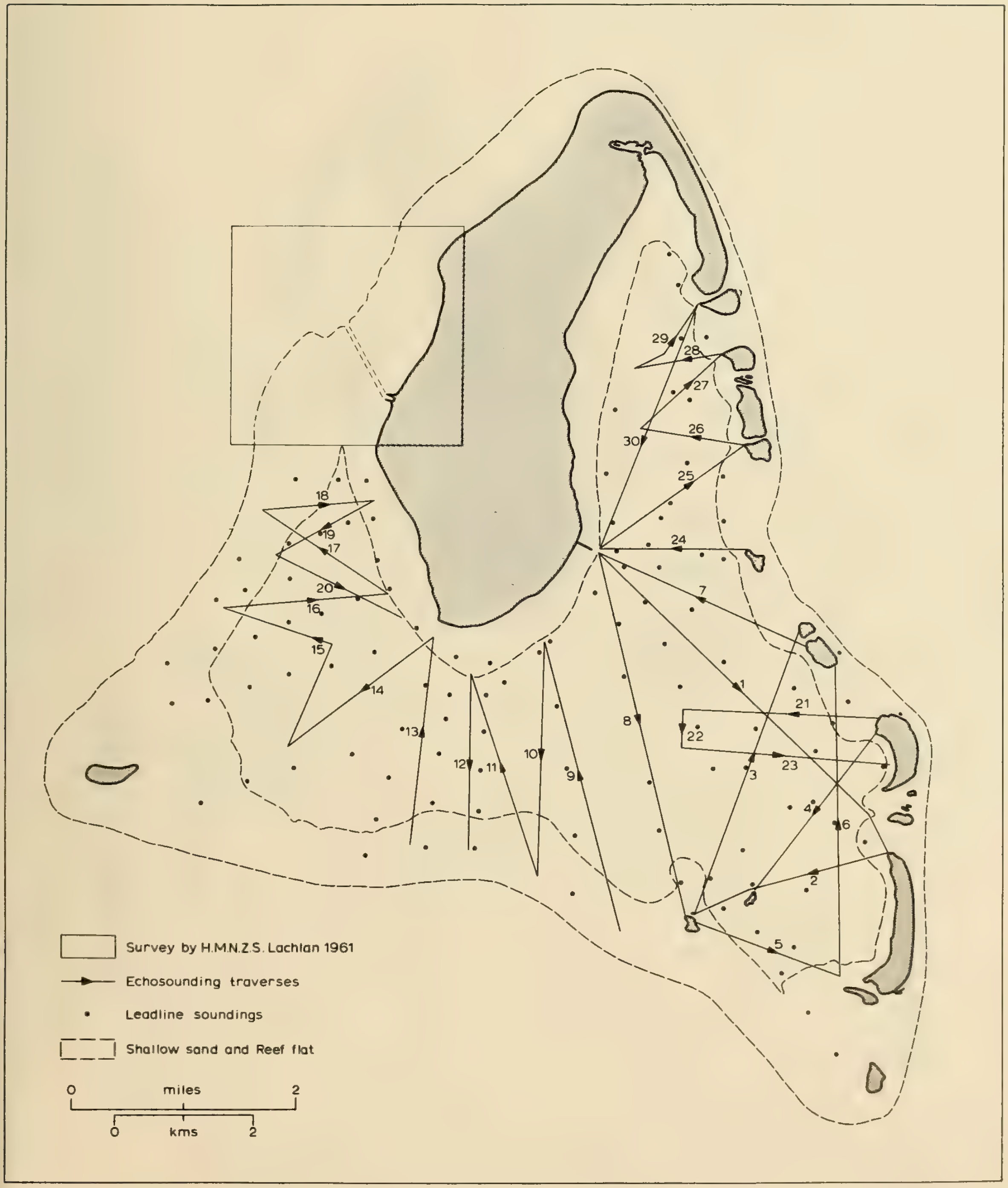


Figure 12. Location of echotraverses and soundings in the Aitutaki lagoon, 1969

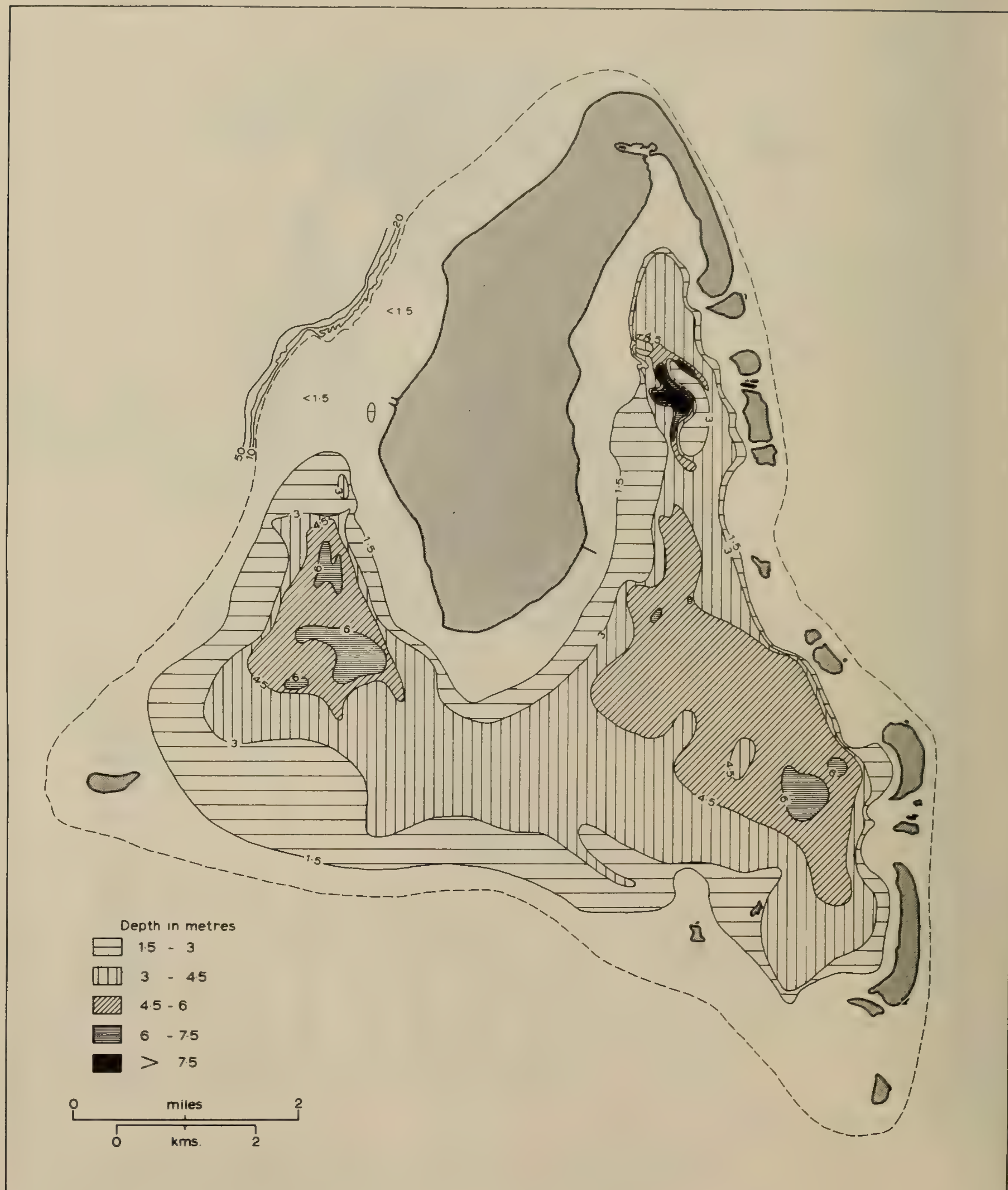


Figure 13. Bathymetry of the Aitutaki lagoon

Figure 14. Types of sediment samples in the Aitutaki lagoon and on the reefs

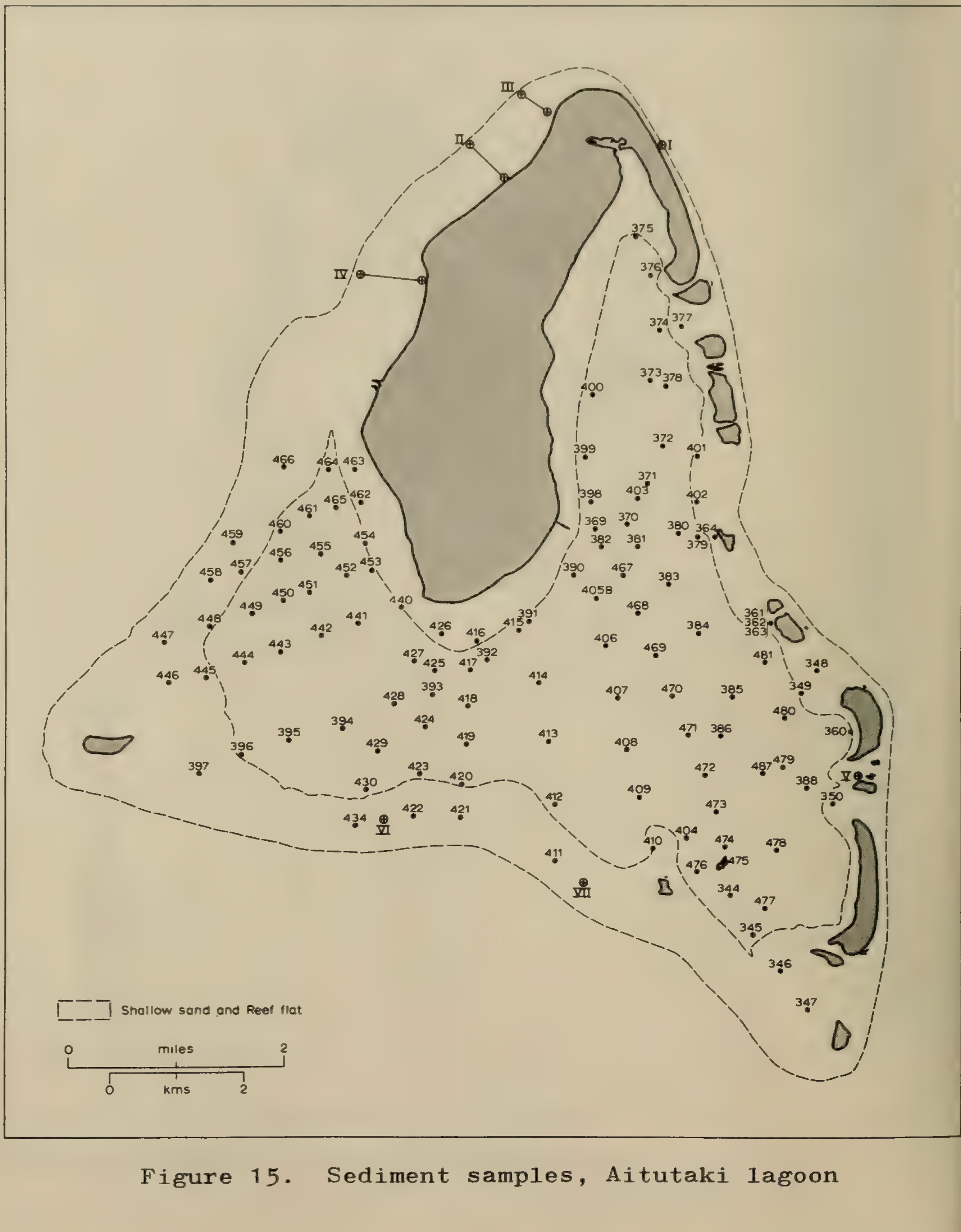


Figure 15. Sediment samples, Aitutaki lagoon

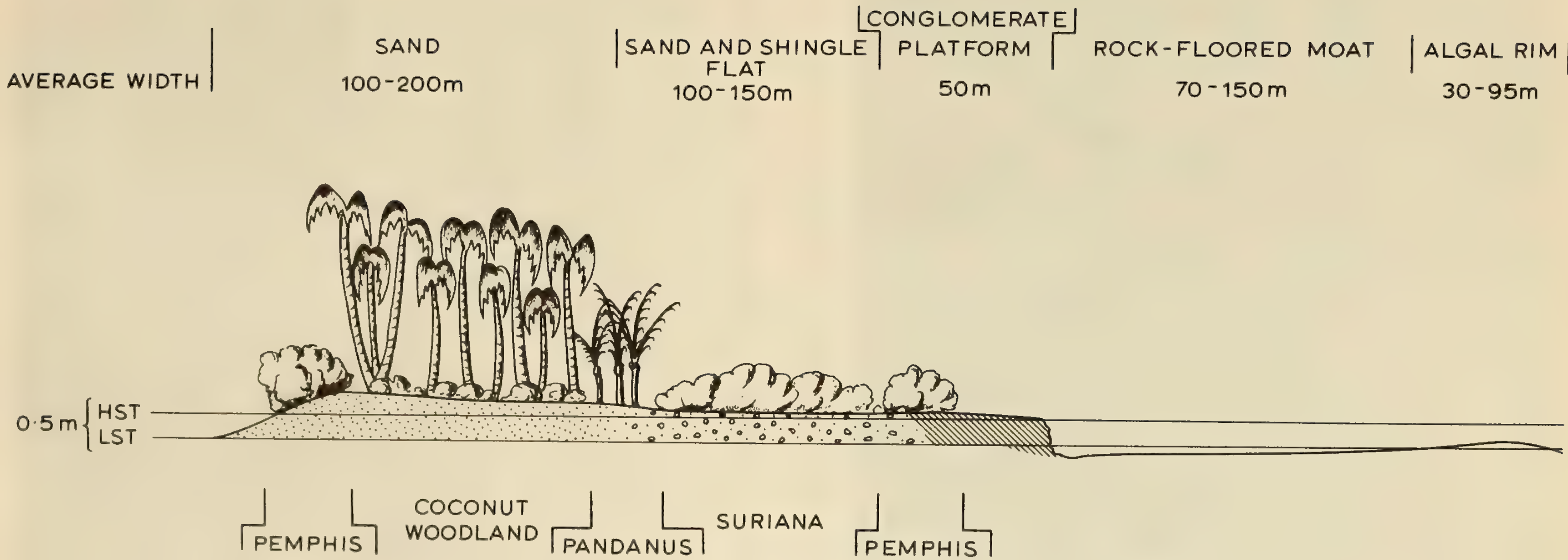


Figure 16. Schematic profile of an eastern reef motu

3 Reef edge at Ootu, looking south

4 Surge channel in the reef edge at Ootu

5 Algal ridge at Ootu

6 Reef block on the reef edge at Atike, northwest coast.
Note the inverted corals in the block.

7 Acropora on the southern reefs near Station VII

8 Conglomerate platform on Angarei, view south

9 Conglomerate platform on Ee, view south

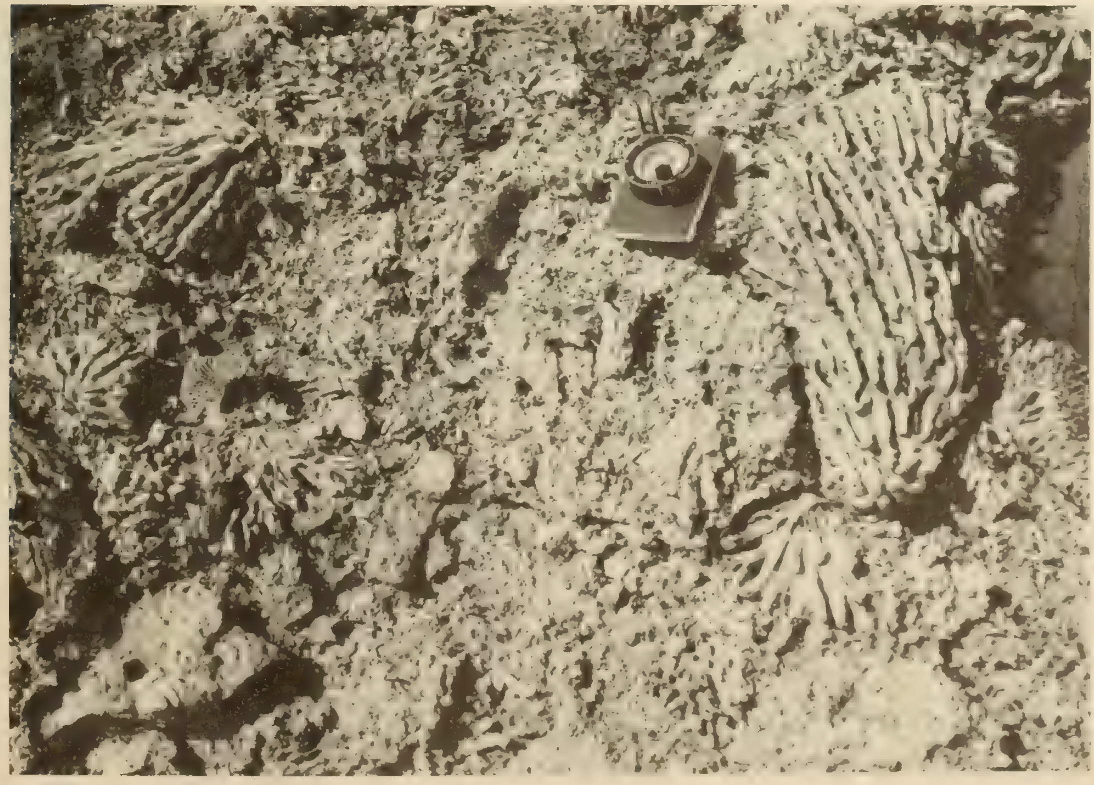
10 Conglomerate platform on Mangere, view north

11 Conglomerate platform, north end of Tavaerua, view south

12 Conglomerate platform, north end of Tekopua, view north

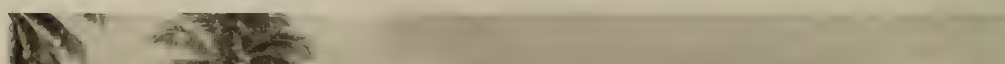
13 Detail of conglomerate platform, Ootu

14 Detail of conglomerate platform, Muritapua



15 Beachrock overlying conglomerate platform, southern end of Keopua

16 Beachrock on the north shore of Maina



17 Inverted reef block, seaward coast of Muritapua

18 Reef block on the seaward coast of Papau

19 Motus from the mainland shore at Vaipeka

20 Sandy lee shore on Akaiami, view south

21 Rubble on the north shore of Angarei

22 Eroded beach section showing humic horizons, north shore of Papau

23 Cliffed west coast of Moturakau, with Furcraea

24 Leeward shore of Rapota

25 South shore of Rapota

3. REEF ISLANDS OF AITUTAKI

D.R. Stoddart

This chapter describes the main physiographic features and the vegetation patterns of the smaller islands of Aitutaki (Plates 19 and 34). Of the sixteen islands, fifteen were mapped by compass traverse and pacing and maps based on these surveys are presented here. All are detrital reef islands (motus) with the exception of one volcanic island, Moturakau; the other volcanic island, Rapota, could not be mapped using the traverse method because of its rugged shoreline topography. In addition to the islands, this account also includes the Ootu peninsula which joins the main island of Aitutaki at its northern end but which in many respects closely resembles the motus. For interpretations of the data presented here, reference should be made to Chapters 2 and 5. The very dissimilar reef islands of Rarotonga have been described elsewhere (Stoddart, 1972).

Ootu (Plates 3-5 and 13)

The Ootu peninsula, entirely composed of carbonate sediments, extends for 3.25 km along the eastern reefs from its junction with the main volcanic island. Its mean width is about 400 m, with a minimum of 250 m; at its widest, near the junction with the main island, it reaches 750 m in width. If separate, it would have been the largest of the Aitutaki motus; Tekopua, the largest, is 2.25 km long. The seaward beach crest rises 2-3 m above high water, and the surface slopes gently to the lagoon; there are no dunes except at the southern point. According to Hochstein (1967), seismic refraction measurements show the reef sediments under Ootu to be 13-20 m thick.

Because of its connection with the main island the peninsula has undergone considerable alteration by man. Two intersecting runways, respectively 1800 and 1500 m long, were constructed during World War II and are still in use. Their construction entailed levelling of the land and clearing of the vegetation adjacent to them. The only woodland remaining is along the lagoon shore and south of the main runway, where there is a less disturbed area approximately 600 m long and 450 m wide. Elsewhere the vegetation is periodically cleared and is restricted to low shrubs, herbs and grasses.

The main vegetation seaward of the main runway is *Scaevola* scrub 1-1.5 m tall, with similar shrubs and occasionally trees (3-5 m tall) of *Tournefortia*. The most frequent tree is *Pandanus*, 3-5 m tall, with *Morinda citrifolia*, and shrubby trees

of Guettarda speciosa and Hibiscus tiliaceus, all cut back from time to time. Much of the ground surface is bare sand with Cassytha filiformis, large erect Portulaca, Heliotropium anomalum, Euphorbia hirta, and several grasses and sedges (Dactyloctenium aegyptium, Cenchrus echinatus, Cynodon dactylon, Fimbristylis cymosa, Cyperus javanicus). The seaward beach is mainly coarse sand with patches of gravel; the outpost vegetation comprises Ipomoea pes-caprae and Triumfetta procumbens. In places near the airstrip there are extensive patches, now relict, of introduced decorative plants such as Gaillardia.

South of the airstrip there is a denser scrub, with Euphorbia chamissonis and Corchorus torresianus up to 1 m tall and occasional small trees of Tournefortia, Guettarda, Morinda, Hibiscus, Leucaena insularum, and, rarely, Pisonia. Capparis is found occasionally; this species is not common at Aitutaki.

Between the scrub and the lagoon shore is a taller woodland, dominated by trees 12-15 m tall of Pisonia grandis, with Hibiscus tiliaceus, Morinda citrifolia, Guettarda speciosa, and coconuts. The ground cover is very sparse, and much of the surface is covered with leaves and coconuts. Groves of Pandanus tectorius occur in the woodland, with trunks up to 3 m tall before branching. Coconut woodland extends along the lagoon side of the Pisonia-Hibiscus woodland. The trees are 15 m tall and there is little undergrowth. There are some massive trees 10 m tall of Guettarda speciosa, and occasional Casuarina. Further north, on the lagoon side of the airstrip, there is a scrub woodland of Hibiscus, Guettarda and Scaevola, with Triumfetta and Vigna, and along the shore itself, extending to the waterline, a belt of Pemphis acidula with Sophora and Suriana. Some swampy depressions near the lagoon shore are unvegetated.

The southern shore of the peninsula has low dunes with Pemphis, Tournefortia and Scaevola, and a ground cover of Fimbristylis and Cyperus. Colubrina asiatica is common in the nearshore scrub.

The vegetation of Ootu is characteristic of the motus in the presence of such species as Scaevola and Tournefortia and of trees such as Guettarda and especially Pisonia. Several species are common on the peninsula, however, but are not found on the motus. These are mostly grasses (Dactyloctenium aegyptium, Cynodon dactylon, Cenchrus echinatus), sedges (Cyperus javanicus), and herbs, often cultivated and weedy species (Spermacoce suffrutescens, Euphorbia hirta, Mimosa pudica, Solanum nigrum, Datura metel, Momordica, Gaillardia).

Akitua (Figure 17)

Akitua is the northernmost of the motus, separated from the southern end of the Ootu peninsula by a channel less than 2 m deep. The island is triangular, 750 m long and up to 310 m wide.

The seaward coast is lined by a discontinuous and irregular conglomerate platform with a maximum exposed width of 50 m; the platform is generally mantled by a recent rubble spread of about the same width. Beaches on the north and south sides are narrow, with overhanging vegetation in places and some cliffing. The only extensive area of unvegetated sand is a lagoonward sand spit 200 m long.

Pemphis scrub forms a zone 50 m on the seaward side of the island, and a narrow fringe along the north and south shores. This is replaced by Suriana scrub on the northeast shore inland of the conglomerate platform. A mixed scrub, dominated by Scaevola but with Tournefortia, Sophora, Suriana, Pemphis, and low trees of Guettarda, is extensive at the west end and in the north.

The centre of the island is covered with Cocos-Guettarda woodland with Morinda, Leucaena and Pandanus. The woodland is open and there is a well-developed shrub layer beneath. This includes Timonius polygama, Corchorus torresianus, Sida rhombifolia and Euphorbia chamissonis. Ground cover is also luxuriant, comprising grasses and sedges (Cenchrus echinatus, Fimbristylis cymosa), fern (Polypodium), and herbs and vines (Ipomoea pes-caprae, I. macrantha, Cassytha filiformis, Triumfetta procumbens, Emilia sonchifolia, Boerhavia repens, Bidens pilosa). Several of these species (e.g. Cenchrus) are uncommon or absent on other motus and are present on Akitua because of its proximity to Ootu: some are only found at the point where the path from Ootu reaches the beach crest.

The only other woodland consists of clumps of Casuarina at the west end and along the south shore. Both Hibiscus and Hernandia are absent. One vegetation type is represented only on Akitua of the Aitutaki motus: a sedge marsh occupying a depression with standing water, and dominated by Cladium jamaicense 2-2.5 m tall.

Angarei (Figure 18, Plates 8 and 21)

Angarei, Ee and Mangere form a group of very similar islands separated by narrow channels and which probably originally formed a single entity. Ee is the largest, and the two islands to north and south closely resemble each other. Angarei has maximum dimensions of 480 and 400 m. It consists of rubble, cobbles and gravel, with unusually narrow lagoon beaches overhung with vegetation. There is a conglomerate platform up to 40 m wide along the seaward coast.

The vegetation is clearly zoned. Pemphis scrub forms a zone up to 50 m wide along the seaward side, and also extends as a narrow fringe around the leeward shores. Few other plants, apart from outpost Triumfetta and Vigna, are found in this zone. Inland of the Pemphis is a zone of Suriana scrub up to 125 m

wide with occasional Tournefortia shrubs. The Suriana is less dense than the Pemphis; the sand beneath is bare, except for trailing Cassytha and occasional Heliotropium. Much of the centre of the island is occupied by a scrub 1-1.5 m tall of Scaevola, with Euphorbia chamissonis and occasional trees of Morinda, Guettarda and Pandanus 2-3 m tall.

Woodland is confined to an area of coconuts and a grove of Casuarina on the northwest side of the island. The coconuts occur with Morinda, Guettarda, and the shrubs Colubrina asiatica and Corchorus torresianus; a single Hernandia seedling was seen. The Casuarina grove is also open and mixed with Guettarda and shrubby Scaevola and Euphorbia chamissonis, with Fimbristylis on bare sand.

Ee (Figure 19, Plates 9 and 28)

The third largest of the Aitutaki motus, and probably formerly connected with Angarei and Mangere to north and south, Ee is 975 m long, parallel to the reef edge, and up to 410 m wide. A conglomerate platform lines the whole of the seaward coast of this rectangular island; it varies in width from 10 to 50 m. The inner parts of the platform are mantled with rubble and boulders: much rubble extends back into the Pemphis zone, and there are boulders 1-1.5 m in diameter even in the woodland. Beaches are very narrow all round the island, and vegetation reaches the sea along most of the lagoon coast.

Pemphis extends almost continuously around the island's shores, as a narrow strip on the lagoon shore and as a zone up to 30 m wide on the seaward side; it is also present along the north and south shores. The most extensive vegetation type is, however, Suriana scrub, extending across the greater part of the island towards its northern and southern ends, and elsewhere forming a zone 50-60 m wide. The scrub is generally 2-3 m tall, and reaches a maximum of 4 m. Other species present include Euphorbia chamissonis and Cassytha filiformis. Further inland other shrubs become more common, including Sophora, Scaevola, and Colubrina, the latter 3-4 m tall. Under this taller scrub is a sparse ground cover of Euphorbia, Fimbristylis and Cassytha.

There are three main types of woodland on the island. Cocos-Guettarda woodland occupies a compact area about 250 m in diameter, with several smaller groves. The trees of Guettarda reach 10 m in height, Pandanus 7 m, and tall shrubs of Colubrina 5 m. Other shrubs in the more open woodland include Scaevola, Suriana and Euphorbia, with Fimbristylis on otherwise bare ground. In the more dense and deeply-shaded woodland, Scaevola is absent and is replaced by Timonius polygama; there are many young coconuts as well as Guettarda and Pandanus. Juvenile Hibiscus is present, and, rarely, individual trees of Pisonia. This woodland is margined by a zone of Pandanus and Guettarda.

No other plants grow in this zone, and the ground is deeply covered with trash of Pandanus leaves. The third woodland type comprises Casuarina groves on the lagoon shore. Low Scaevola, Suriana and Euphorbia are found in these open groves, with Heliotropium, grasses, Triumfetta and Vigna. One Leucaena tree was seen.

Mangere (Figure 20, Plate 10)

A small island south of Ee, with maximum length and breadth of about 350 m, Mangere comprises a seaward continuous conglomerate platform 35-55 m wide, a rubble spread, and a leeward sandy area. Beaches are almost non-existent on the lee side, where vegetation reaches the sea.

The vegetation consists mainly of low scrub with a leeward area of coconut woodland. Pemphis forms a zone up to 30 m wide on the seaward side of the island, and a narrow fringe on the lagoon shores. The most extensive scrub is dominated by Suriana maritima, in a zone up to 130 m wide, replaced inland by a more mixed scrub, dominated by Scaevola, with Tournefortia and some Pemphis, Guettarda and Pandanus. Most of the scrub is 2-3 m tall; some of the seaward Pemphis reaches 4 m. The coconut woodland is distinctly taller, with much Guettarda up to 8 m. Other trees include Pandanus and Leucaena. In more open areas there is extensive scrub beneath the trees, mainly Scaevola about 1 m tall but in places reaching 2 m, and Timonius polygama reaching 2.5 m. Euphorbia chamissonis forms a lower dwarf scrub, and other plants beneath the woodland include Fimbristylis, Triumfetta and Tacca. Polypodium is common in more deeply shaded places. The narrow leeward beaches have an outpost vegetation of Ipomoea and Vigna with Heliotropium and occasional Tournefortia.

Papau (Figure 21, Plates 18 and 22)

Papau is a small isolated island, rather irregularly shaped, 400 m long and 200 m wide, with a discontinuous dissected conglomerate platforms 35-75 m wide on its seaward side. Coral rubble and boulders are scattered along the seaward shore, but sand and gravel beaches are better developed here than on the islands to the north. The rubble includes large boulders of Porites 1.5 m in diameter. Large blocks, many of them more than 1 m in diameter, are found well inland as well as on the shore. The island reaches a height of 2-2.5 m above sea-level. On the north coast the shore is being eroded, revealing a sequence of soil horizons covered by storm sands and gravels. The sequence is:

Surface	
Humic pebbly sand with roots	13 cm
White fine sand	15 cm
Dark humic sand with roots	5 cm
White fine sand	10 cm
Black humic sand with roots	13 cm
Coarse gravel	18 cm
Fine white sand to beach	100 cm +

For so small an island the vegetation is of some interest. The usual z ne of *Pemphis* is here narrow and discontinuous on the seaward side, with an average width of only 10 m. There is some indication that its width has been reduced by shore retreat. The *Suriana* zone, with some *Sophora*, has a more normal width of up to 130 m. On the leeward side there is an area of coconut-*Guettarda* woodland 8-15 m tall. Other trees include *Pandanus*, low *Morinda*, and *Leucaena*. Shrubs beneath the woodland are *Timonius polygama*, *Scaevola* (to 1.5 m), *Sophora*, and *Euphorbia chamissonis*, with on the surface *Stenotaphrum*, *Fimbristylis*, *Portulaca*, *Cassytha* and *Lepidium bidentatum*. Within the coconut woodland is an area of tall, closed-canopy broadleaf woodland, consisting mainly of *Pisonia grandis*, *Hernandia* and *Guettarda*. The ground surface in this woodland is mainly covered with trash, with *Triumfetta* and *Polypodium*, and occasional *Tacca* and sedges. There is some leeward beach scrub of *Scaevola* and *Tournefortia*, with *Heliotropium* and *Ipomoea*.

Tavaerua Iti (Figure 22)

A small island immediately north of Tavaerua, Tavaerua Iti is rather regularly shaped, 250 m in maximum length (transverse to the reef) and 210 m wide. The reef edge lies 120 m to seaward. The outer 60 m of the reef platform comprises a boulder zone, the inner 60 m a moat 0.5-1 m deep. The outer 45 m of the moat is sand-flored, but the inner part is bare rock, with outliers of the conglomerate platform near shore. Small patches of the conglomerate platform extend between the two islands, and it is possible that they were formerly connected. On the seaward side of the island the conglomerate platform is low and dissected, with an irregular outline; it is unusually narrow (a few metres wide), except where it extends lagoonward along the north and south shores. Assuming its continuity beneath the seaward rubble spread with *Pemphis*, its maximum width is about 55 m. The island is mainly formed of coral rubble, with narrow leeward beaches, and a lobe of coarse sand on the northern side.

About one-third of the island is wooded, and the rest is covered with scrub. _Pemphis_ forms a continuous zone on the seaward side, up to 25 m wide and 2 m tall. Inside this there is a zone of _Suriana_, also 2 m tall but with a maximum width of about 60 m. Towards the sea this is fairly pure, but inland it becomes more open, with _Euphorbia chamissonis_, _Triumfetta procumbens_, _Vigna marina_ and _Ipomoea macrantha_. The transition between the scrub and the woodland is formed by a dense thicket of _Pandanus_ fringing the taller coconut woodland on its seaward side. The latter includes tall _Guettarda_ and _Pandanus_, juvenile _Hibiscus_, _Timonius polygama_ up to 5 m tall, _Euphorbia chamissonis_, _Tacca_, and, on the ground, _Boerhavia_, _Fimbristylis_, grasses and _Polypodium_. The leeward beaches are fringed by mixed woodland of _Pandanus_ and _Guettarda_, a grove of _Casuarina_ 6 m tall, _Scaevola_ and _Euphorbia chamissonis_, and outpost _Heliotropium_. There is evidence of burning of the vegetation, especially of _Pandanus_ thickets.

Tavaerua (Figure 23, Plate 11)

Tavaerua closely resembles Taverua Iti, but is larger: the island is 290 m wide and 500 m long. The conglomerate platform on the seaward side is intricately dissected, with promontories and deep inlets and many separate outliers. It reaches 30 m in width but much of it is only a few metres wide. It does not extend far lagoonward on the north and south coasts. The leeward beaches are sandy, and in the south over 10 m wide; on the lagoon shore there is some erosion and cliffing, and patches of gravel and rubble.

The seaward _Pemphis_ zone, 50 m wide, has shrubs up to 5 m tall. The _Suriana_ zone within, 80 m wide, is rather lower. About half of the island is occupied by coconut-_Guettarda_ woodland, with _Pandanus_. In spite of the size of the woodland there are no other big trees. _Pandanus_ forms an exclusive thicket round the seaward side of the woodland, at the junction with the _Suriana_ scrub. In the woodland there are seedlings of _Morinda_, young _Guettarda_ 2-5 m tall, dense _Scaevola_ scrub up to 1.5 m tall, _Timonius polygama_ commonly reaching 1-2 m, and _Euphorbia chamissonis_. _Cassytha_ is present but is not common. On the lagoon coast there is a tall scrub of _Suriana_ (up to 3 m tall), _Tournefortia_ (to 2 m) and _Timonius_, with _Euphorbia chamissonis_, _Triumfetta_, _Heliotropium_ and _Fimbristylis_. The ground surface is higher along the lagoon side, and falls towards the seaward margin of the woodland to the rubble and gravel spreads under the seaward scrub.

Akaiami (Figure 24, Plates 20 and 27

The second largest of the motus, Akaiami was formerly used as a base for the Solent flying-boat service, and resthouses, refuelling depot and customs building were erected there (Wood and Hay, 1970, p. 37). Little trace now remains of these,

though there are remnants of old jetties on the lagoon shore. The island is 1120 m long and up to 410 m wide. Unlike most of the other motus it has a prominent seaward beach ridge of gravel and cobbles, and for much of the seaward shore this overlies and obscures the conglomerate platform. Where exposed this is 30-65 m wide, and dissected by inlets. There is an extensive separate remnant of the platform south of the island. Wide sand beaches extend round the leeward side of the island; the lagoon beach ridge is 0.6 m high and 50 m wide, and the interior of the island is somewhat lower. There is a small exposure of near-shore beach rock on the south coast.

Unusually, Pemphis scrub is not well developed on the seaward side of the island: it forms a narrow fringe in the north of the island, and a zone 10 m wide in the south, where the conglomerate platform is widest; it is absent along much of the seaward beach ridge, and is most extensive at the southwest point. Suriana scrub too is weakly developed: it forms a narrow zone on the seaward beach ridge, with outpost Heliotropium, Euphorbia chamissonis, Triumfetta and grasses. The place of Pemphis and Suriana is taken by Scaevola scrub, forming a zone up to 30 m wide and 1 m tall, with occasional Tournefortia to 2 m, along the seaward side. Euphorbia chamissonis and Capparis cordifolia are also present. This scrub terminates landward in a zone of tall massed Pandanus at the fringe of the coconut woodland.

In more open parts of the woodland there are trees of Morinda up to 6 m tall and of Guettarda up to 8 m. Timonius and Euphorbia chamissonis are common low shrubs, with Tacca, Vigna, Fimbristylis and grasses on the ground. Thomson (1968) has described fertiliser experiments on coconuts in the southern part of the island. He found that of 247 palms aged 2-75 years only 67 were bearing nuts, 27 were beyond bearing age, and the rest were unproductive and too crowded. Yield was only 10.7 nuts per bearing palm. With different fertilisers on 0.75 acre experimental plots he obtained yields of 23.9-47.8 nuts per tree. Elsewhere the woodland is more dense and the ground more shaded. Morinda and Guettarda are both much lower, and Polypodium replaces the sedges and grasses on the ground. Near the seaward margin of the woodland Guettarda increases in density until it forms a zone 3-5 m wide immediately inland of the Pandanus fringe, normally about 10 m wide.

Muritapua (Figure 25, Plates 14, 17 and 29)

Muritapua is a small island between Akaiami and Tekopua, 360 m long transverse to the reef edge, and 150 m wide. It has a very irregular seaward conglomerate platform up to 95 m wide, which is scattered with large boulders, mostly of single coral colonies; one of Porites measures 2 x 1.7 x 1.5 m. Most of the surface of the island is formed of gravel and cobbles, with sand beaches on the leeward side, in places formed of mainly Halimeda sand.

The seaward Pemphis zone, up to 50 m wide, is well-developed, with standing in prominent windrows oriented at 280°. Pemphis also occurs intermittently round the lee shores, with Heliotropium and occasional Scaevola. Many of the Pemphis bushes are covered with Cassytha. The most extensive vegetation type is Suriana scrub, surrounding the small central area of woodland on all sides except the north where it is replaced by Scaevola. The scrub contains low Scaevola, some Pemphis, Euphorbia chamissonis and juvenile Pandanus, with Ipomoea macrantha, Triumfetta and grasses on the largely bare ground surface. Cassytha is common, especially on Scaevola. The main area of coconut woodland is only 100 m in diameter, with trees 8-12 m tall. There are patches of Euphorbia and Scaevola beneath the trees, with a sparse ground cover of Triumfetta, Tacca, Fimbristylis, grasses and Polypodium. The surface under the woodland is irregular, with old beach ridges and coral blocks up to 0.6 m long scattered over the gravel and cobbles. Seaward of the coconut woodland is a fringe of Guettarda, 6-7 m tall, with some Pandanus.

Tekopua (Figure 26, Plates 12, 15 and 30)

Tekopua is the largest of the motus, 2250 m long parallel to the reef edge, with an average width of 300 m and a maximum width of 480 m. The seaward reef flat is 150-200 m wide, and consists mostly of a rock-floored moat up to 1 m deep with a higher algal rim. The seaward coast of the island is lined by a continuous conglomerate platform, undissected in the north but crenulate and irregular in the south, with a maximum width of 65 m. In places the conglomerate platform comprises parallel ridges with pronounced seaward dip and landward-facing scarps; some of these are composed of sand rather than gravel and are probably beach rocks. The inlets in the conglomerate platform contain high densities of Holothuria atra, with up to 20 per sq m.

As at Akaiami the conglomerate platform is overlain by a pronounced seaward beach ridge rather than by a flat rubble spread, and the usual Pemphis scrub zone is absent. Pemphis is present only as tall spreading open-branched shrubs on the south coast. Suriana forms a continuous zone along the seaward side, up to 65 m wide, with few other species represented apart from occasional Tournefortia and Pemphis. Low Suriana, with Scaevola, Tournefortia, and in the south Sophora, also forms a narrow fringe on the lagoon shore. Most of the island is covered with a dense coconut woodland. Other trees present include very common Guettarda; tall Hernandia, especially towards the south; Leucaena; Morinda; and trees of Tournefortia 12-14 m tall. These latter are now overtopped by coconuts and Hernandia and are not reproducing. They are more common on the seaward side of the woodland, and may indicate a recent extension of the coconuts. Juvenile trees and low shrubs beneath the woodland include Pipturus argenteus, Timonius polygama, Colubrina asiatica, Hernandia, Sophora, Scaevola, and Euphorbia chamissonis.

Tacca is common, and Capparis is present. The coconuts are more actively managed in the north of the island, where the undergrowth is burned and the ground is largely bare apart from scattered Vigna, Heliotropium, Tacca, Euphorbia and grasses. Elsewhere the woodland is much more dense, and grades into a mixed coconut-Pandanus-Guettarda thicket. Towards the south there is an area of pure Pisonia woodland measuring 520 x 200 m, with tall trees 3-4 m apart, growing on a rubble surface covered with rotting trunks and other trash. Pisonia trees up to 20 m tall are also found in the adjacent coconut woodland, with Morinda, Guettarda and Pandanus and an undercover of Euphorbia. At the southwest point there is a developing sandspit with a zonation of vegetation types outwards from the coconut woodland of: low Scaevola with Cassytha and Euphorbia; tall Pemphis; low Suriana. Apart from clumps of Fimbristylis and some Cenchrus the ground surface is bare.

Terrestrial invertebrates were collected on Tekopua during the Expedition by Wise (1971, pp. 58-60).

Tapuaeta (Figure 27, Plate 33)

Tapuaeta is a small island south of Tekopua, from which it is separated by a deeply scoured channel opening lagoonwards. The island is aligned transverse to the reef-edge, and is 570 m long and up to 210 m wide. It is entirely built of sand, with its surface standing about 1.5 m above sea level. The beaches are sandy, except for cliffed eroded sectors on the north, east and south shores. Beach rock outcrops at several places, with a prominent line 160 m long extending offshore to the southwest.

Coastal scrub comprises mainly Pemphis in the east, with elsewhere Scaevola and Tournefortia with Sophora. These all form a narrow fringe round a mixed woodland dominated by coconuts which covers most of the island. A dense woodland of coconut and Guettarda, floored with coconut trash and Polypodium, becomes more open to the west, where juvenile coconuts 3-4 m tall are scattered through a scrub of Scaevola and Euphorbia with juvenile Pandanus, Guettarda and Morinda, and, on the ground, Tacca, Vigna, Portulaca, sedges and grasses. Towards the east the coconuts are taller and closer, with massive trees of Hernandia sonora and Guettarda. There is an understorey of Hernandia seedlings, Hibiscus tiliaceus and Morinda, and a ground layer of Vigna, Cassytha and Euphorbia. Trees of Pisonia grandis are present in this woodland, but they do not form a distinct vegetation type.

The island is uninhabited, but there are wild pigs in the woodland.

Sand cay south of Tapuaeta (Figure 28)

A small sand cay south of Tapuaeta is 190 m long and up to 70 m wide. It is entirely built of sand. The vegetation is restricted to a low scrub of Suriana maritima, with two low bushes of Tournefortia. There is no conglomerate platform and no beach rock.

Motukitiu (Figure 29, Plates 26 and 31)

Motukitiu is the southernmost island on the eastern reef. It is 450 m long and 300 m wide, with a narrow seaward conglomerate platform or ledge covered by a wide spread of largely unvegetated fresh gravel and cobbles up to 100 m wide.

There are patches of wind-sheared Pemphis mostly less than 2 m tall, with the largest shrubs reaching 3 m, forming a zone up to 40 m in width, on the northern part of this gravel spread, close to the sea, but the most extensive scrub is formed by Suriana maritima. This forms a zone up to 95 m wide, occupying about one-third the width of the island, with shrubs rising inland to a height of 4 m. The Suriana is mainly a pure stand with scattered Tournefortia. In pioneer situations seaward of the Suriana zone, on the rubble flat, there are low bushes of Suriana and Scaevola 1-2 m apart and numerous seedlings of Heliotropium anomalum. The Suriana zone passes landward through a fringe of Pandanus and Guettarda into coconut woodland. This averages 100 m in width. Guettarda and Pipturus are common under the coconuts, Morinda is rather rare. The ground cover comprises Boerhavia tetrandra, Triumfetta procumbens, Ipomoea macrantha, Vigna marina, grasses and Polypodium. Capparis cordifolia is present but rare. On the lagoon coast there is a wide sand beach, with Scaevola up to 2 m tall, Polypodium, grasses and sedges, and outpost Triumfetta and Heliotropium. Low shrubby trees of Cordia are present on the beach crest in the north.

Wise (1971, pp. 58-60) collected terrestrial invertebrates on Motukitiu in 1969.

Moturakau (Figure 30, Plate 23)

One of the two small volcanic islets on the southern reef rim, Moturakau is 460 m long in a north-south direction and 120 m wide. The core of the island is a steep ridge of volcanic rocks 160 m long on the east side of the island, extended in an abrasion platform cut in volcanic rocks for 100 m to the south. Wood and Hay (1970, p. 38) describe the volcanic rocks as comprising 9 m of well-bedded agglomerate containing palagonitic ash, angular basalt and coral fragments, mostly dipping 10^{o} toward the west. Carbonate sands extend the island to the west and south of this volcanic core.

The vegetation is very different from that of the other reef islands. On the west side of the ridge, on volcanic soil, is a dense woodland of Calophyllum inophyllum 40-50 m wide, with Guettarda, Morinda, Leucaena and some Hibiscus tiliaceus. Calophyllum is not found on the normal reef islands. The woodland is deeply shaded, and ferns are plentiful on the ground and boles of trees. This woodland is surrounded by a coconut-Hibiscus woodland, especially towards the southern point. Under the trees there is some low Scaevola, together with Vigna marina and grasses. The steep eastern slope of the volcanic ridge is vegetated with tall Fourcraea and some Hibiscus, with Polypodium in crevices, and also tall Pandanus tectorius. There are vines of Abrus precatorius over the bare rock. Beach vegetation on the leeward side is more typically that of the motus, with patches of Sophora and Pemphis, and outpost Ipomoea pes-caprae and Vigna, but no Suriana or Tournefortia.

The island was formerly used as a leper colony but is now uninhabited. Magnetic samples were collected here during the 1969 Expedition by Lumb and Carrington (1971).

Rapota (Plates 24 and 25)

The main island consists of a rounded hill of basalt surrounded by large basalt boulders, which form the shorelines. These boulders are set in a calcareous matrix up to about 1.5 m above sea level on the south coast. Marshall (1930, p. 40) recorded nephelinite and basalt from this island. Wood and Hay (1970, p. 38) record 1.8 m of "flow-banded nephelinite ... on a subhorizontal weathered zone in porphyritic limburgite. The weathered zone is 6 to 8 in thick (15-20 cm) and yellowish brown in colour. Also present in agglomerate on Rapota Island are pebbles of trachyte and phonolite, presumably erupted during a late stage in the volcanic history of Aitutaki."

The island is covered with a dense woodland of Calophyllum inophyllum with tall trees of Hernandia, Cocos, Casuarina and Morinda, with Pandanus, Hibiscus and Thespesia. The ground cover consists of Polypodium, Tacca, Vigna marina, Abrus precatorius and grasses. Two small islets offshore also have trees of Calophyllum, Pandanus and Cocos; that to the north also has Guettarda, Thespesia and Scaevola, and that to the east Hibiscus and Pemphis. Otherwise Rapota lacks some of the most common plants of the motus. Mature trees of Erythrina variegata and Mangifera indica suggest that the island was formerly inhabited.

Magnetic samples were collected here during the 1969 Expedition (Lumb and Carrington, 1971), and also terrestrial invertebrates (Wise, 1971, pp. 58-60).

Maina (Figure 31, Plate 16)

Maina is a true sand cay located near the southwestern reef

point of Aitutaki. It is a sandy island 710 m long and 310 m in maximum width. There is no counterpart of the conglomerate platforms of the eastern motus, but beach rock is widely if discontinuously exposed along the foot of beaches. These latter are exceptionally wide for Aitutaki, reaching 40 m in the southwest.

Most of the island is covered with a tall open scrub. At the eastern end and along the north shore this comprises *Scaevola* (1-1.5 m tall) and *Tournefortia* with *Guettarda*. The scrub is rather open and the ground surface bare except for *Fimbristylis* and *Cassytha*. The western end of the island is occupied by a scrub 1.5-2 m tall of *Suriana maritima* with occasional *Tournefortia* reaching 2 m. Other shrubs such as *Scaevola* and *Colubrina* are also present, but patchily. The ground surface is again rather bare, with *Cassytha*, grasses, *Portulaca*, and some *Euphorbia chamissonis*. The open coconut woodland near the centre of the island includes *Hibiscus* and *Pandanus*; shrubs such as *Scaevola* and *Colubrina*; and, on the surface, mainly *Triumfetta*, *Heliotropium* and *Cassytha*, with *Tacca*, *Portulaca*, *Euphorbia*, *Polypodium* and grasses.

The island is uninhabited, but there is a light tower on the south coast, erected in 1954. Wise (1971, pp. 58-60) collected terrestrial invertebrates here during the 1969 Expedition.

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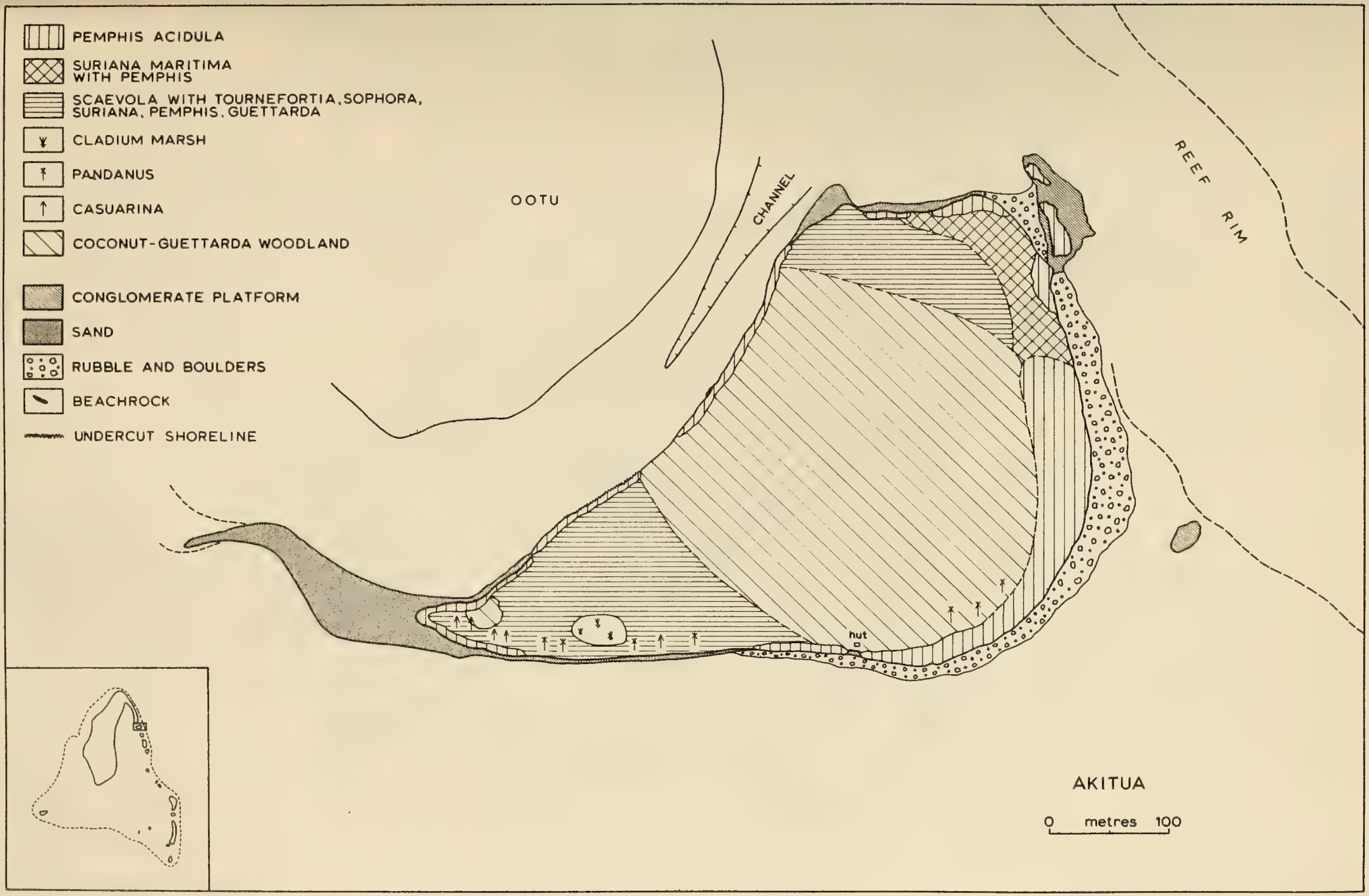

Figure 17. Akitua

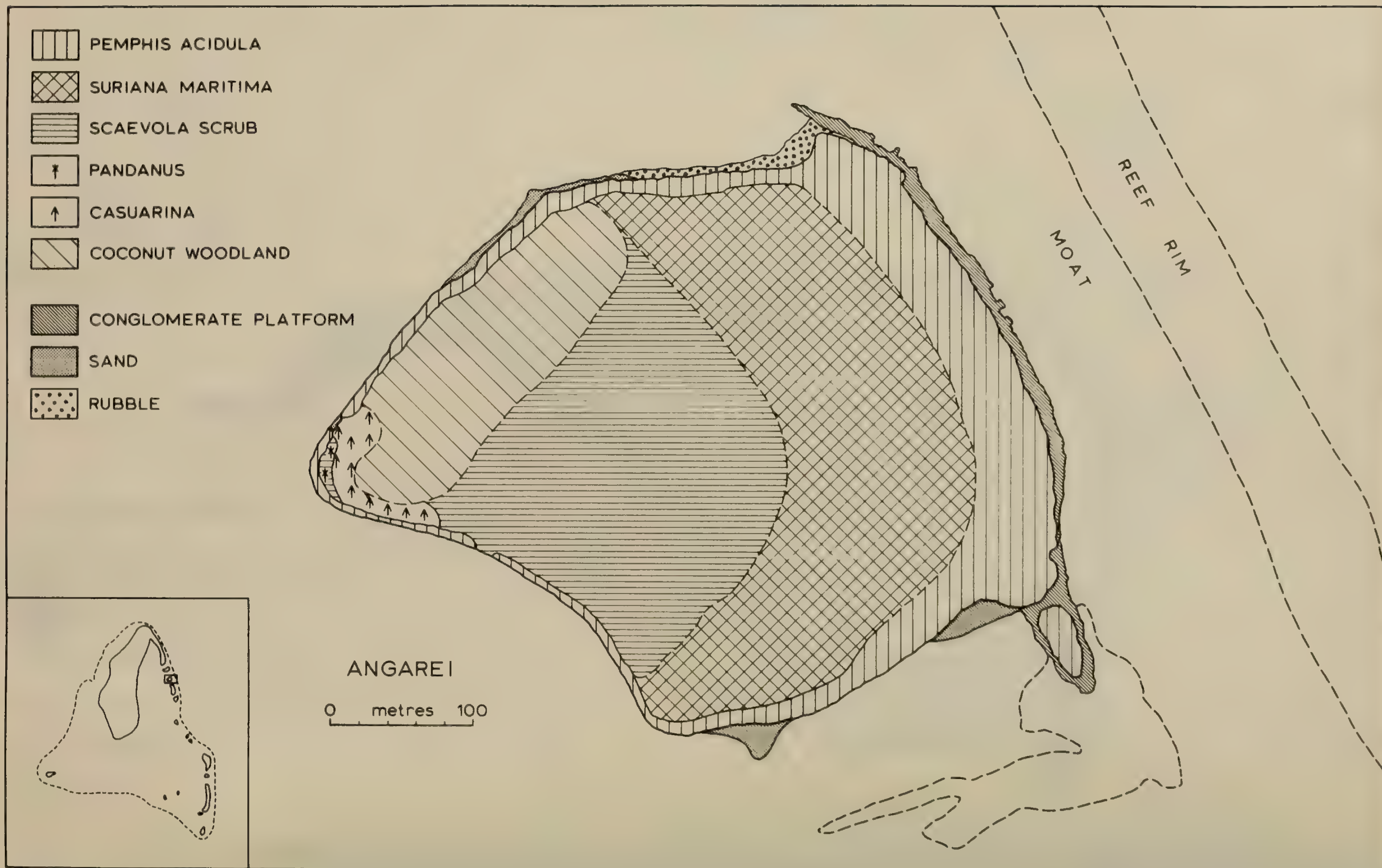

Figure 18. Angarei

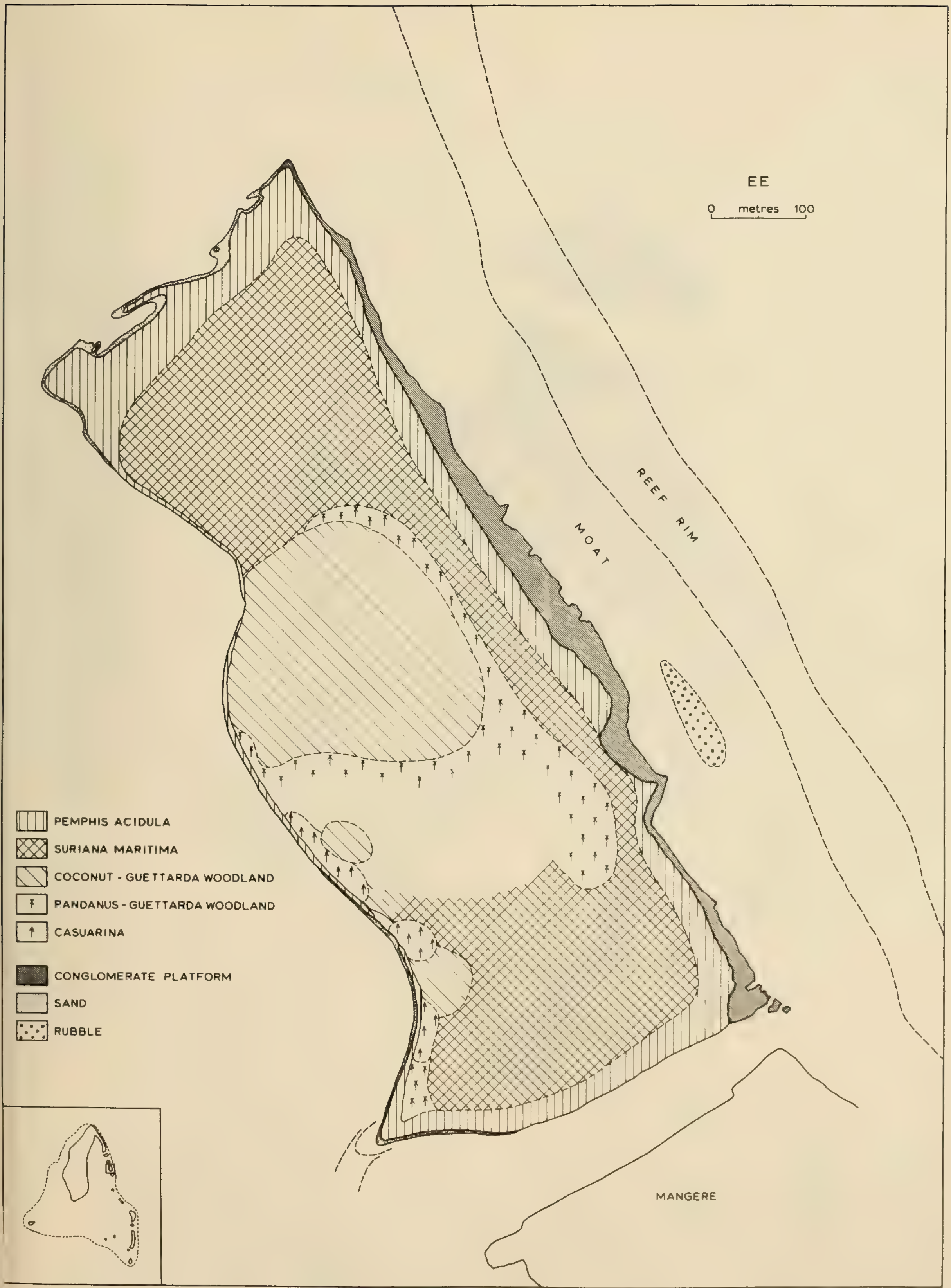
EE
0 metres 100
REEF RIM
MOAT
PEMPHIS ACIDULA
SURIANA MARITIMA
COCONUT - GUETTARDA WOODLAND
PANDANUS - GUETTARDA WOODLAND
CASUARINA
CONGLOMERATE PLATFORM
SAND
RUBBLE
MANGERE

Figure 19. Ee

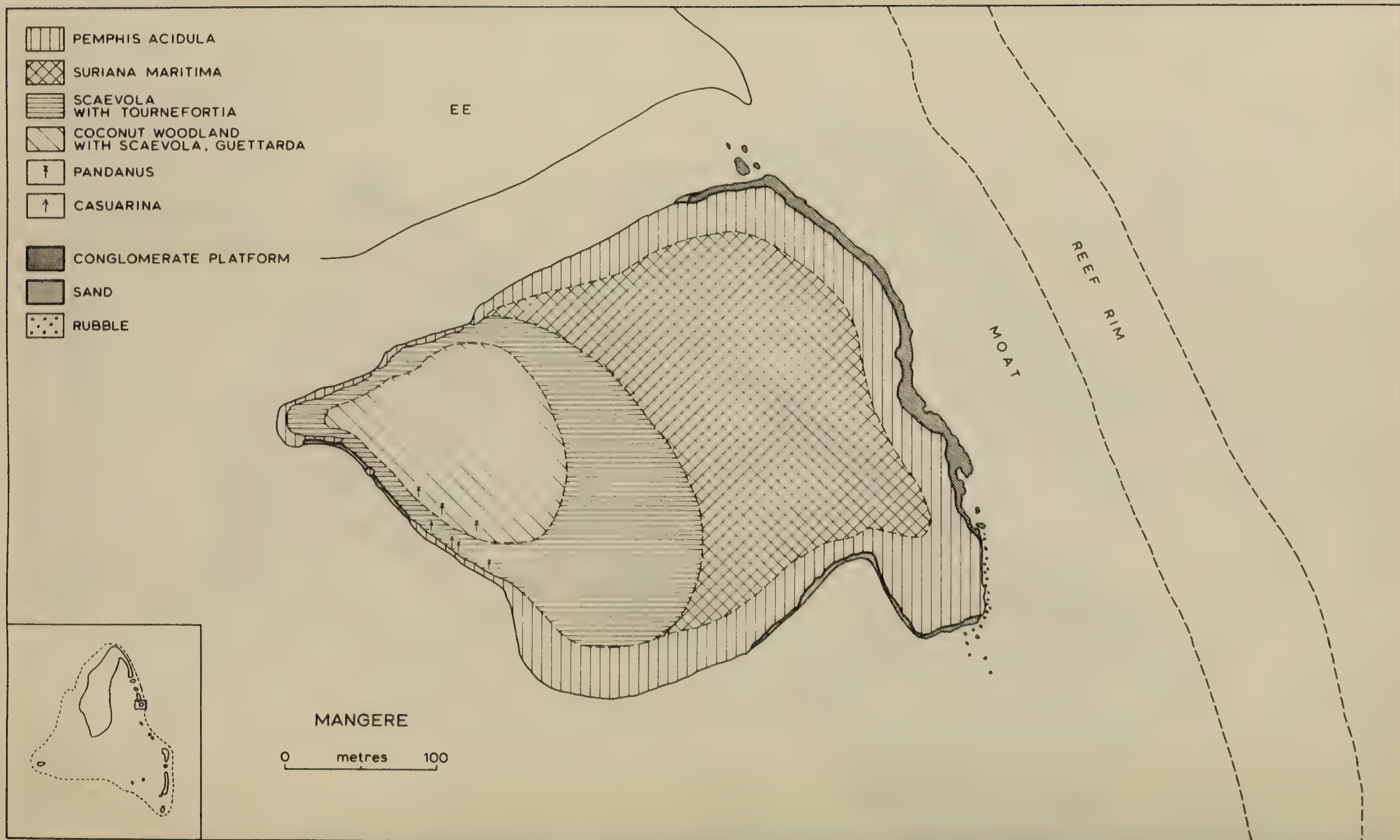

Figure 20. Mangere

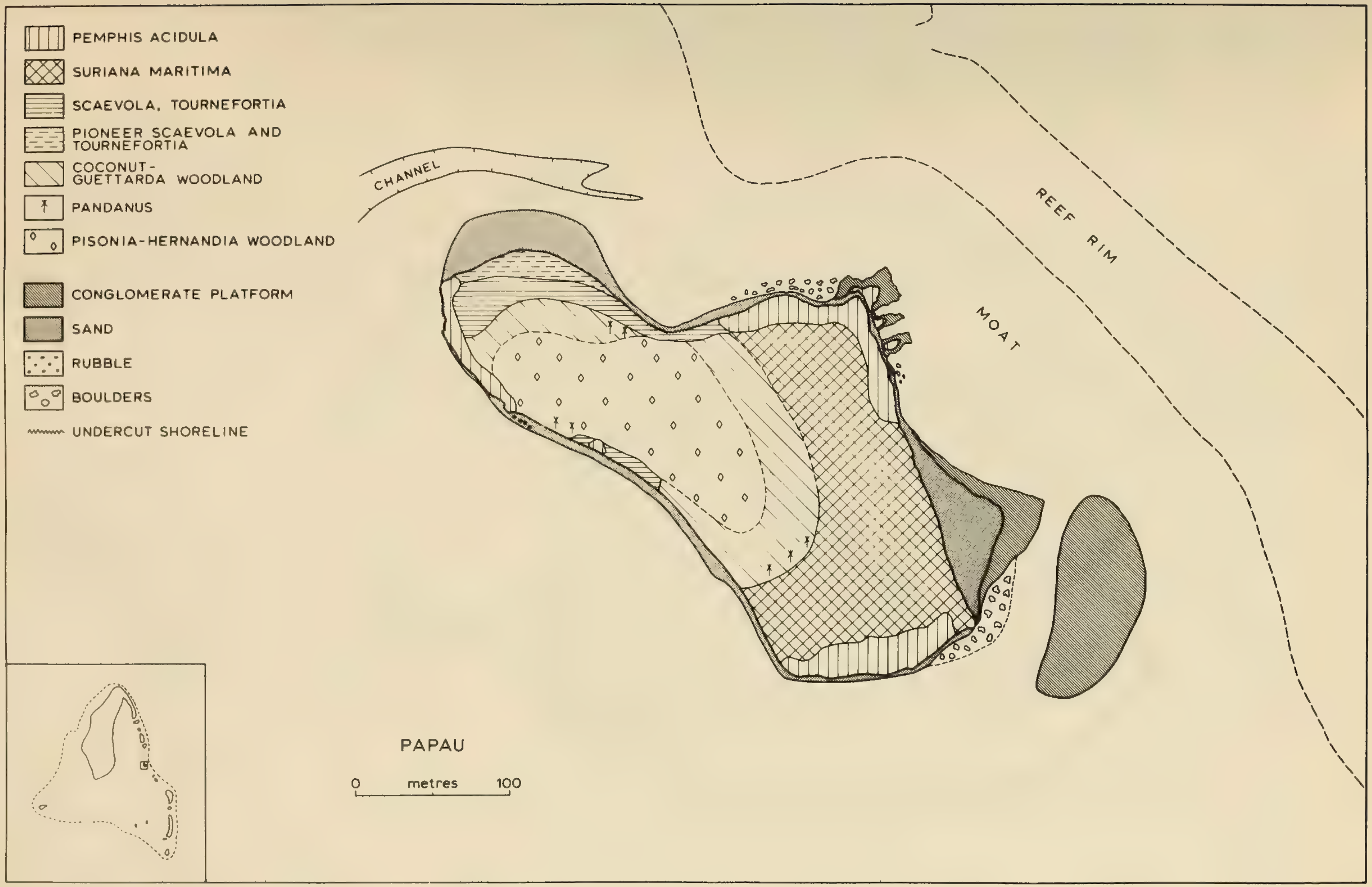

Figure 21. Papau

Figure 22. Tavaerua Iti

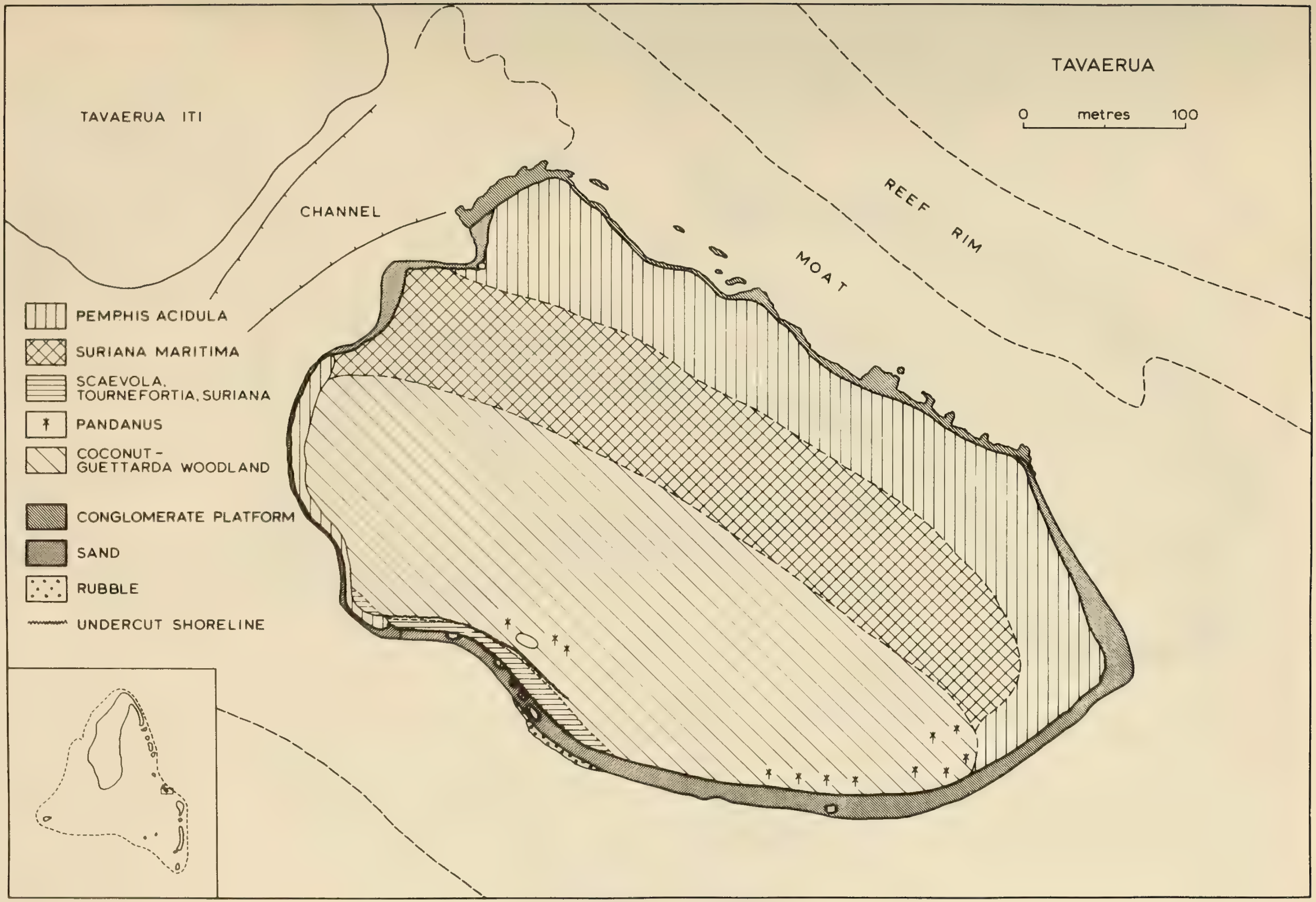

Figure 23. Tavaerua

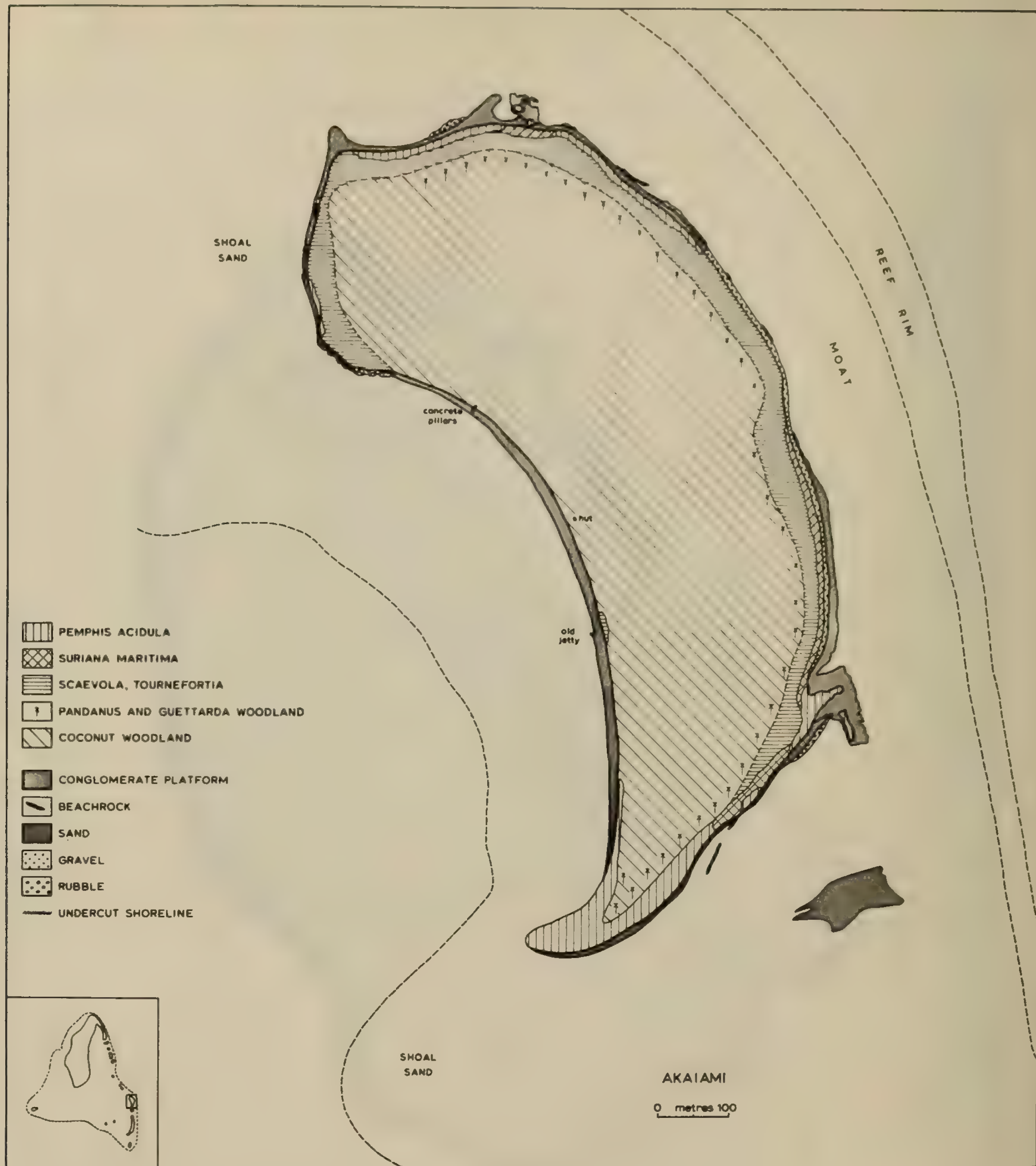

Figure 24. Akaiami

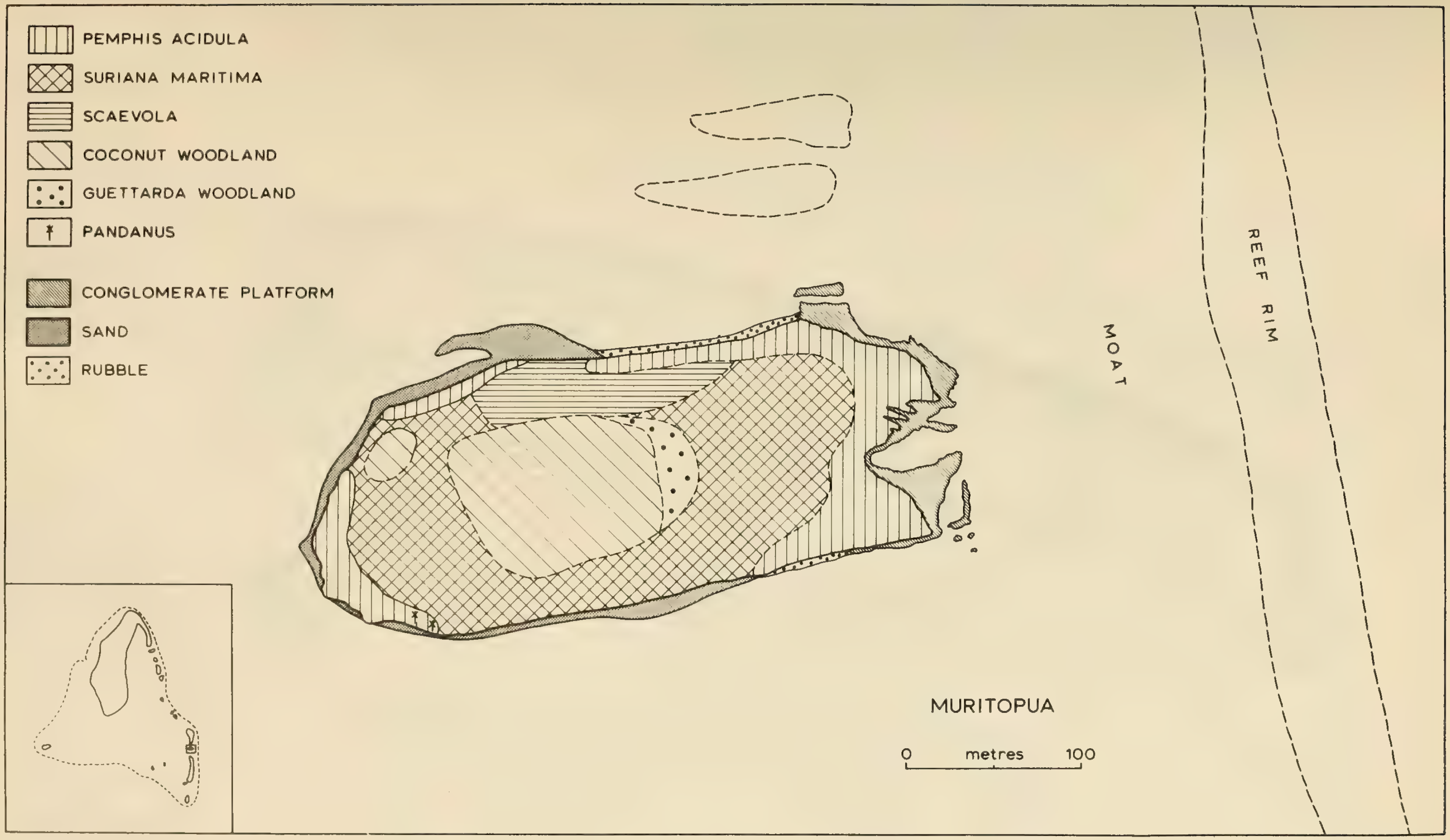

Figure 25. Muritapua

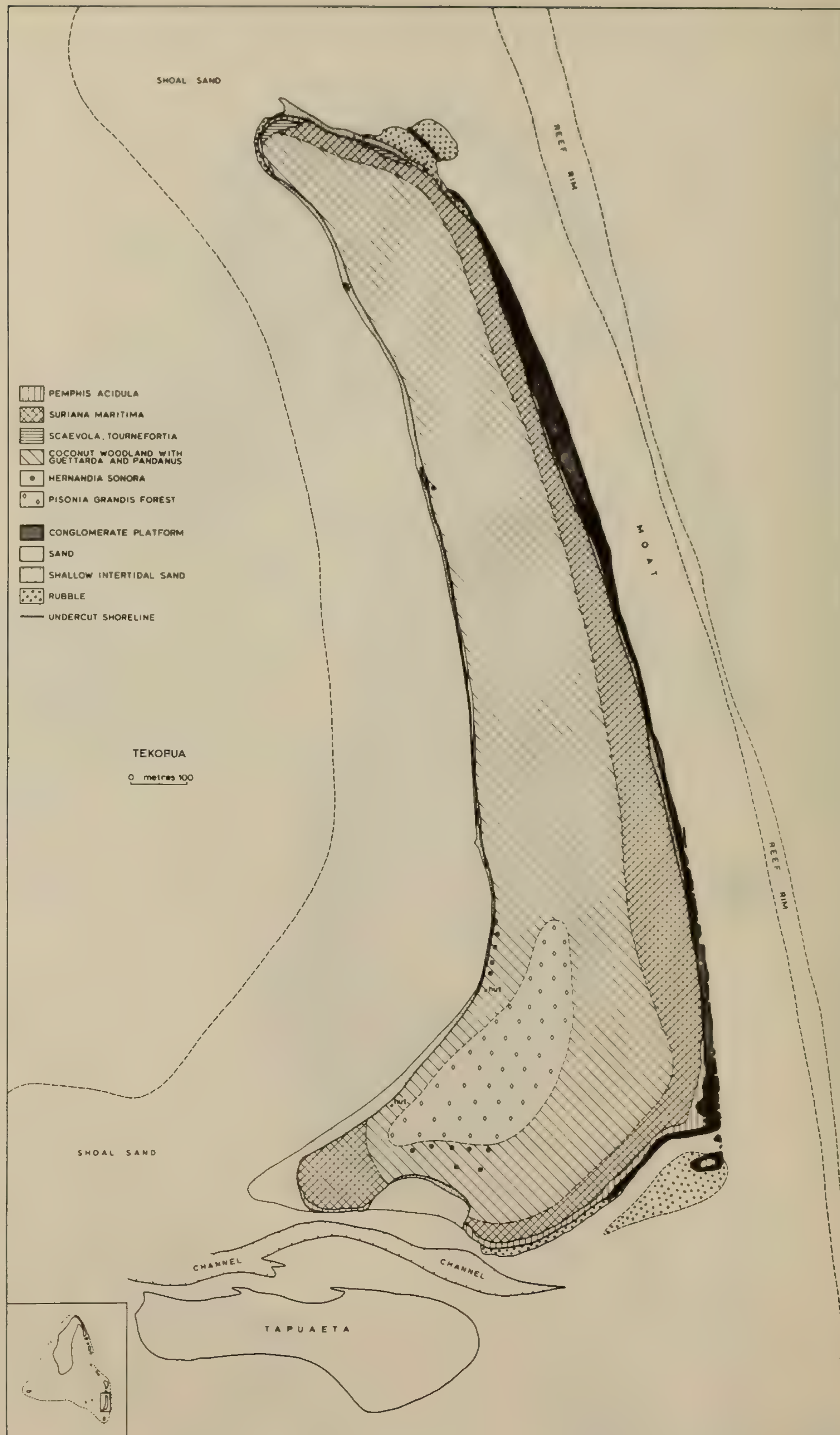

Figure 26. Tekopua

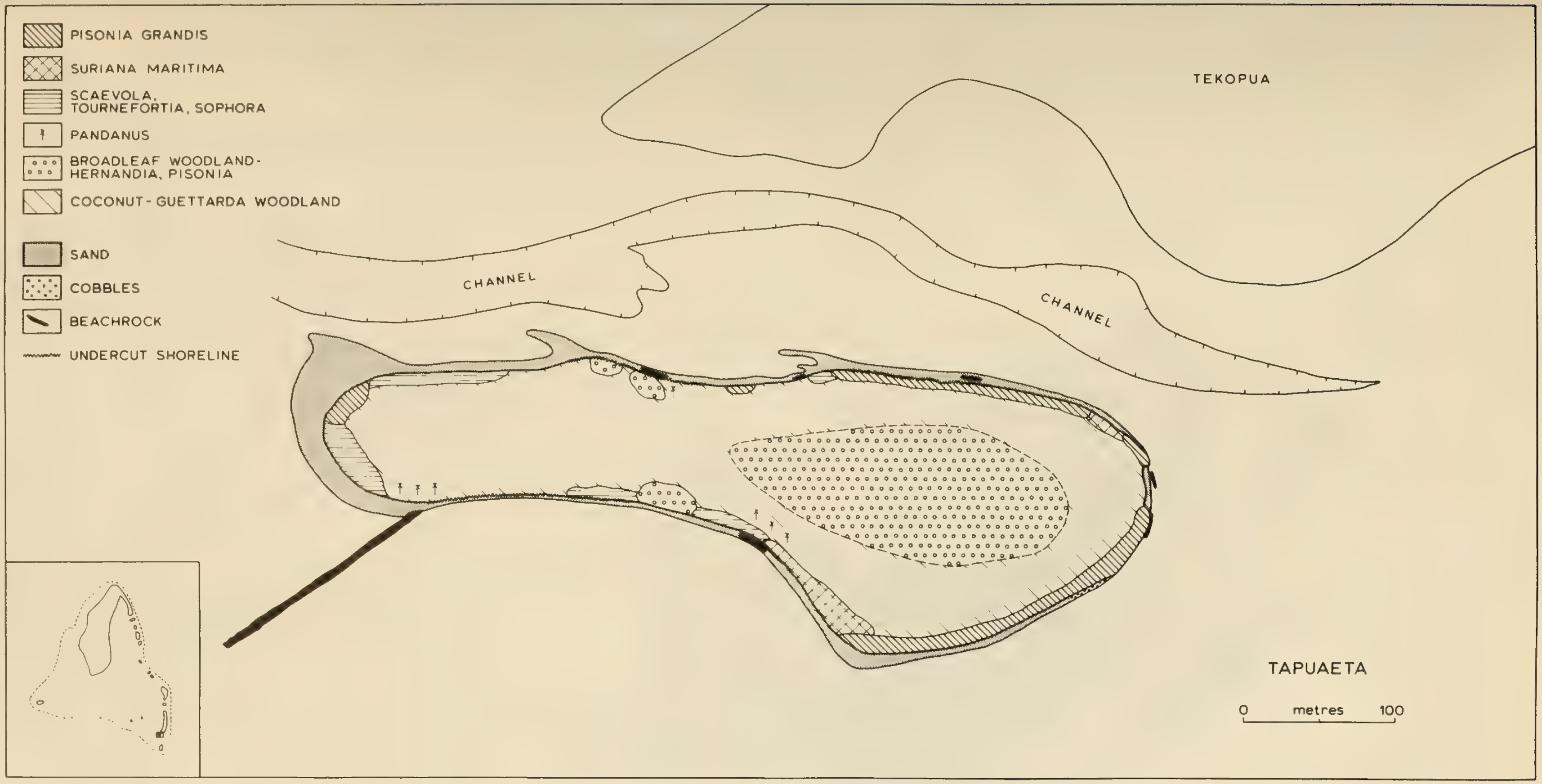

Figure 27. Tapuaeta

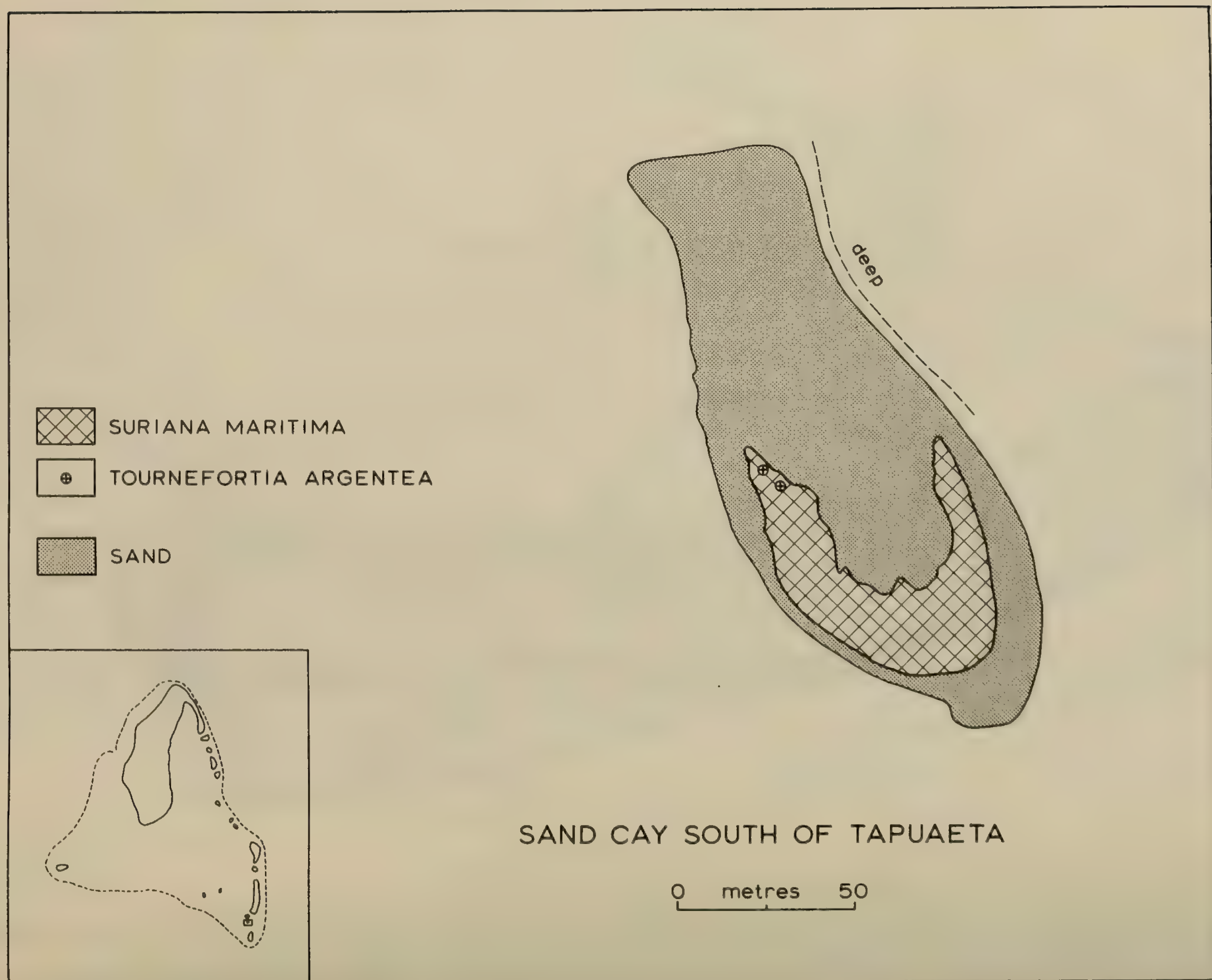

Figure 28. Sand cay south of Tapuaeta

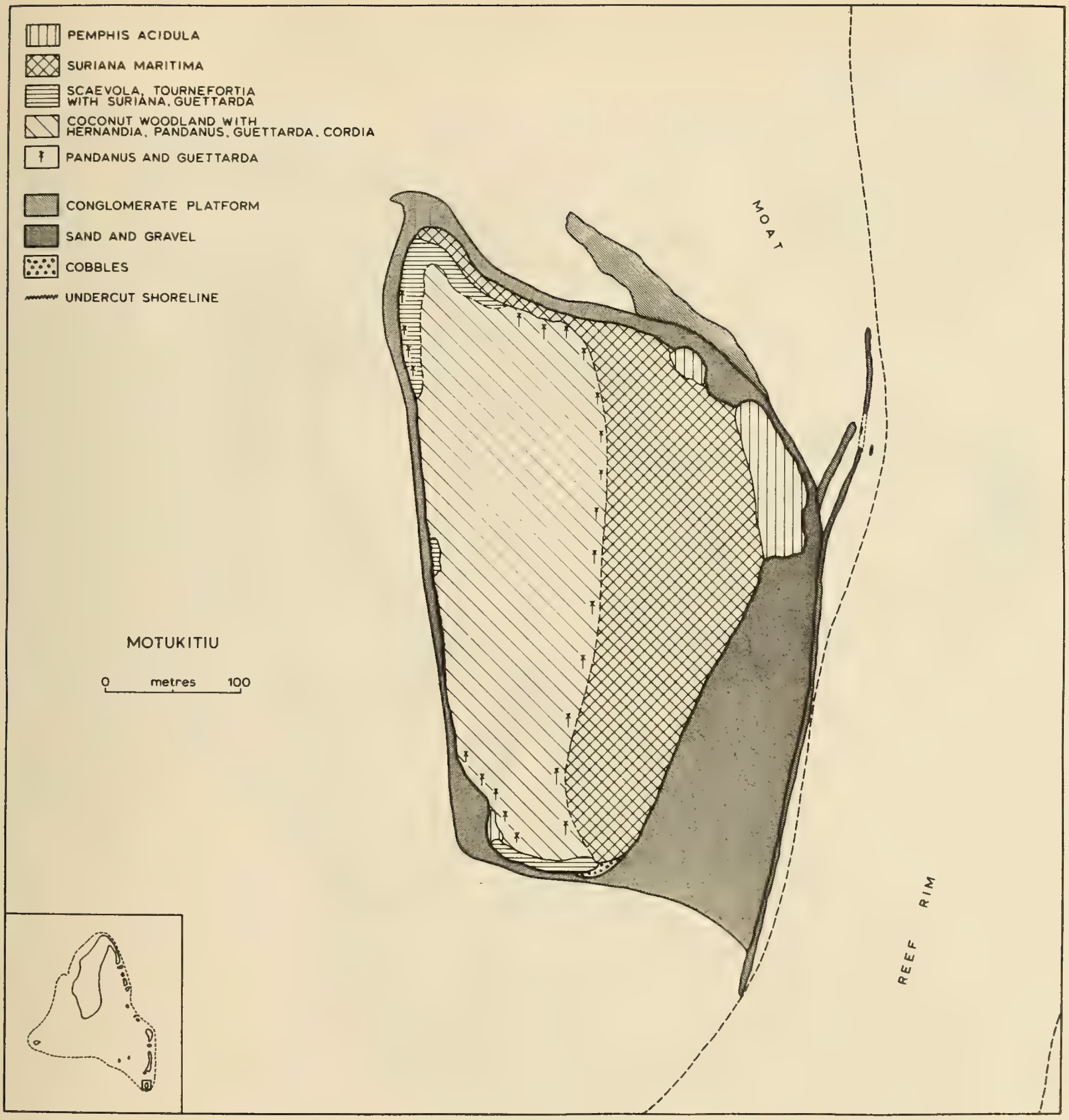

Figure 29. Motukitiu

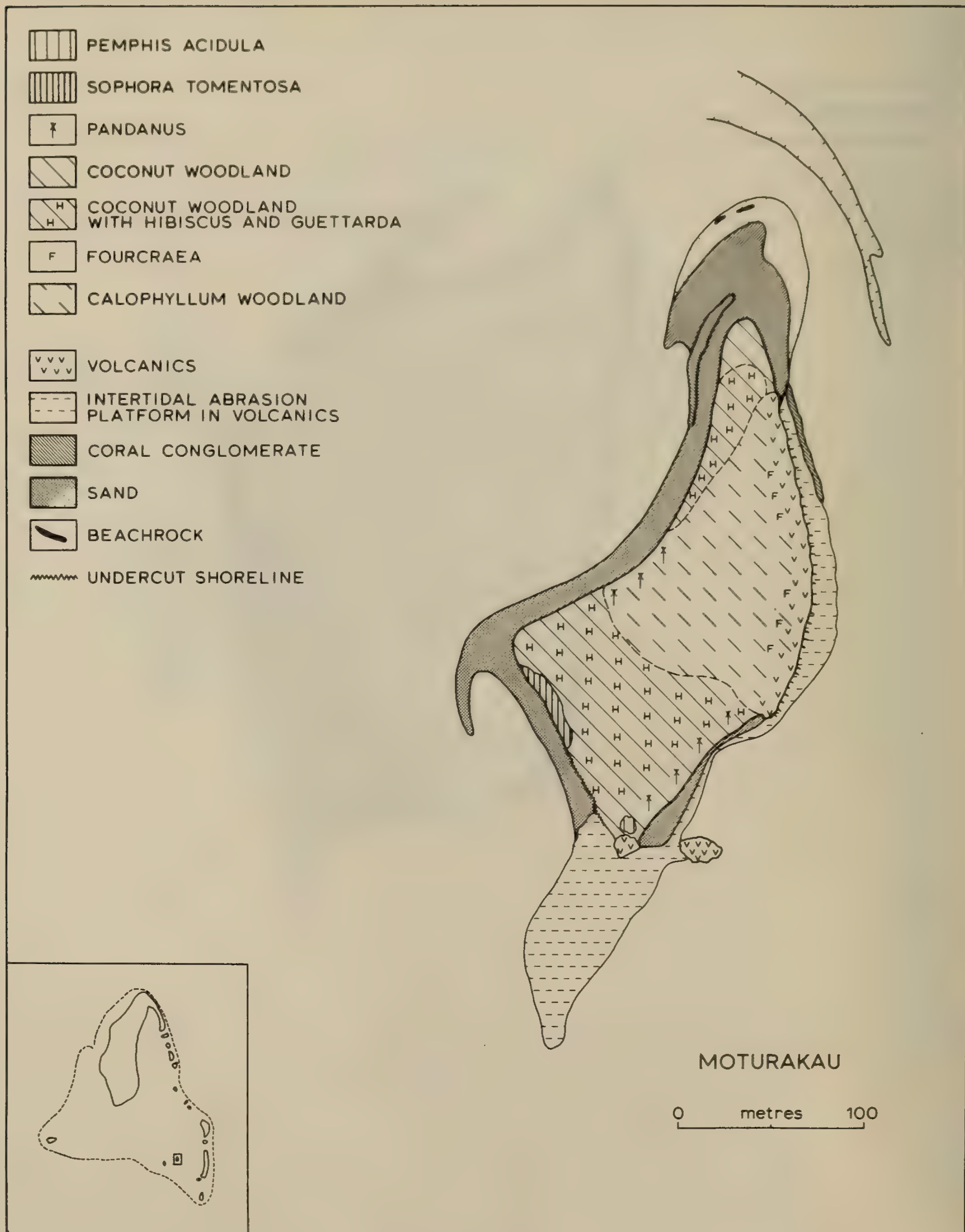

Figure 30. Moturakau

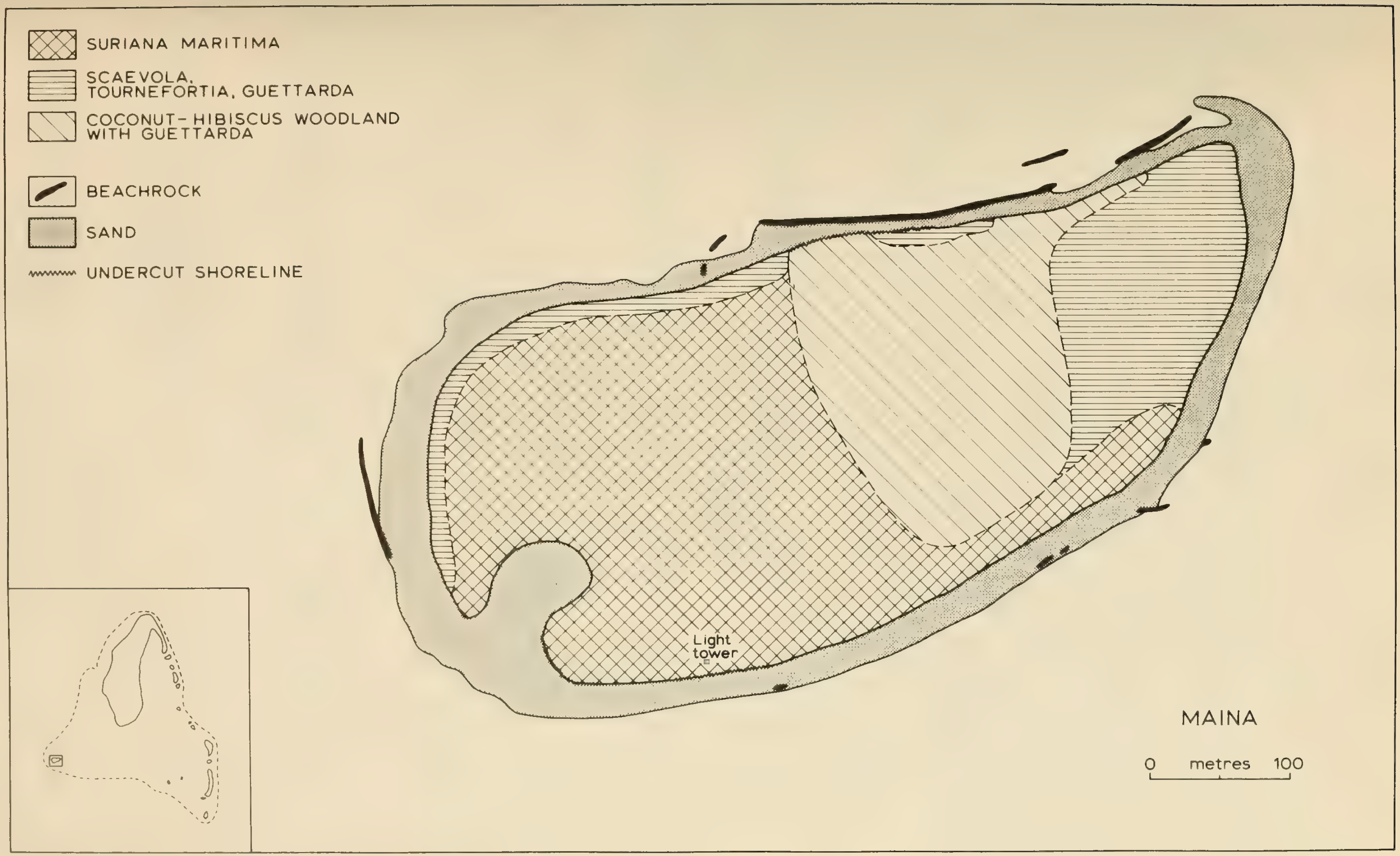

Figure 31. Maina

4. VASCULAR PLANTS OF AITUTAKI

F.R. Fosberg

Cheeseman (1903) and Wilder (1931) have published floras of Rarotonga, and Philipson (1971) has commented on collections made on that island in 1969. No list has previously been published for Aitutaki. Ferns collected on Aitutaki in 1969 are included in the treatment of ferns of the Cook Islands by Brownlie and Philipson (1971). The following list is mainly of plants collected on the main island of Aitutaki, but some plants from the reef islands are included; it may be compared with the list of plants from the reef islands of Rarotonga published by Fosberg (1972). Collecting localities are shown in Figure 32. Plants marked + are considered indigenous, those marked ø are considered aboriginal introductions, and those marked * recent introductions.

PSILOTACEAE

+ Psilotum nudum (L.) Beauv.
  Teaitu, Stoddart 2332 (US, CANTY, BISH).

POLYPODIACEAE

+ Nephrolepis hirsutula (Forst.f.) Presl
  Vaipae, Stoddart 2230 (US, CANTY); Anaunga, Stoddart 2266 (US, CANTY).

+ Polypodium scolopendria Burm.f.
  Akitua, Stoddart 2223 (US, CANTY).

+ Thelypteris forsteri Mort. (?)
  Anaunga, Stoddart 2265 (US, CANTY); Aretere, Stoddart 2333 (US, CANTY).

ARAUCARIACEAE

* Araucaria heterophylla (Salisb.) Franco
  Aremati, Stoddart 2298 (US, CANTY, BISH).

PANDANACEAE

+ Pandanus tectorius Park.
  Ootu, Stoddart 2225 (US).

GRAMINEAE

* Cenchrus echinatus L.
  Ootu, Stoddart 2210 (US, CANTY).

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* Coix lachryma-jobi L.
Vaipae, Stoddart 2245 (US, CANTY, BISH).

* Cynodon dactylon (L.) Pers.
Ootu, Stoddart 2192 (US, CANTY).

* Dactyloctenium aegyptium (L.) Willd.
Ootu, Stoddart 2191 (US, CANTY).

* Digitaria ciliaris (Retz.) Krel.
Ootu, Stoddart 2193 (US, CANTY).

ø Echinochloa colonum (L.) Beauv.
Vaipae, Stoddart 2227 (US), Stoddart 2242 (US, CANTY, BISH).

* Panicum maximum Jacq.
Vaipae, Stoddart 2235 (US, CANTY, BISH).

\+ Panicum reptans var. marquesensis (Brown) Fosb.
Anaunga, Stoddart 2267 (US, CANTY, BISH).

\+ Paspalum distichum L.
Arutanga, Stoddart 2292 (US).

ø Paspalum orbiculare Forst.
Vaipae, Stoddart 2242a (US).

* Sorghum bicolor (L.) Moench
Maungapu Hill, Stoddart 2276 (US, CANTY, BISH).

* Sporobolus africanus (Poir.) Robyns and Tourn.
Anaunga, Stoddart 2264 (US, CANTY, BISH); Maungapu Hill, Stoddart 2283 (US, CANTY).

\+ Stenotaphrum micranthum (Desv.) Hubb.
Papau, Stoddart 2346 (US, CANTY, BISH).

CYPERACEAE

\+ Cladium jamaicense Crantz
Akitua, Stoddart 2218 (US, CANTY, BISH).

* Cyperus alternifolius L.
Arutanga, Stoddart 2289 (US, CANTY, BISH); Rangiteia-Pata, Stoddart 2319 (US, CANTY, BISH).

* Cyperus brevifolius (Rottb.) Hassk.
Vaipae, Stoddart 2241 (US).

\+ Cyperus javanicus Houtt.
Ootu, Stoddart 2178 (US, CANTY, BISH).

* Cyperus cyperoides (L.) O.Ktze.
Vaipae, Stoddart 2226 (US, CANTY); Rangiteia-Pata, Stoddart 2320 (US).

\+ Fimbristylis cymosa R.Br.
Ootu, Stoddart 2180 (US, CANTY), Stoddart 2187 (US, CANTY, BISH); Rangiteia-Pata, Stoddart 2321 (US, CANTY).

PALMAE

ø Cocos nucifera L.
Widespread on main island and on all reef islands.

ARACEAE

ø Colocasia esculenta (L.) Schott
Stoddart, sight; main island.

* Xanthosoma sagittifolia (L.) Schott (?)
Aretea, Stoddart 2314 (US, CANTY).

COMMELINACEAE

* Commelina diffusa Burm.f.
Rangiteia-Pata, Stoddart 2325 (US).

LILIACEAE

* Gloriosa superba L.
Arutanga, Stoddart 2285 (US, CANTY).

AMARYLLIDACEAE

* Crinum procerum Carey
Teaitu, Stoddart 2316 (US, CANTY).

AGAVACEAE

ø Cordyline fruticosa (L.) Chev.
Maungapu Hill, Stoddart 2295 (US, CANTY).

* Furcraea probably F. foetida L.
Moturakau, Stoddart, sight.

TACCACEAE

ø Tacca leontopetaloides (L.) O.Ktze.
Teaitu, Stoddart 2331 (US, CANTY); Tapuaeta, Stoddart 2343 (US).

MUSACEAE

ø Musa sp.
Stoddart, sight.

CANNACEAE

* Canna indica L.
Vaipae, Stoddart 2255 (US, CANTY, BISH).

CASUARINACEAE

+ Casuarina equisetifolia L.
Ootu, Stoddart 2179 (US, CANTY, BISH).

URTICACEAE

+ Pipturus argenteus (Forst.f.) Wedd.
Motukitiu, Stoddart 2340 (US, CANTY, BISH).

MORACEAE

ø Artocarpus altilis (Park.) Fosb.
Aretea, Stoddart 2312 (US).

Ficus sp.
Arutanga-Aretea road, Stoddart, sight.

NYCTAGINACEAE

+ Boerhavia repens L.
Akitua, Stoddart 2222 (US, CANTY, BISH).

+ Boerhavia tetrandra Forst. (?)
Motukitiu, Stoddart 2342 (US, CANTY, BISH); Taverua Iti, Stoddart 2345 (US, CANTY, BISH).

+ Pisonia grandis R.Br.
Ootu, Stoddart 2174 (US, CANTY).

AMARANTHACEAE

+ Achyranthes canescens R.Br.
Motukitiu, Stoddart 2341 (US, CANTY, BISH).

PORTULACACEAE

* Portulaca oleracea L. (?)
Ootu, Stoddart 2196 (US, CANTY, BISH).

LAURACEAE

+ Cassytha filiformis L.
Ootu, Stoddart 2177 (US, CANTY).

* Persea americana L.
Aretea, Stoddart 2315 (US, CANTY, BISH).

HERNANDIACEAE

+ Hernandia sonora L.
Teruarei, Stoddart 2261 (US, CANTY).

CAPPARIDACEAE

+ Capparis cordifolia Lam.
Ootu, Stoddart 2297 (US, CANTY).

CRUCIFERAE

+ Lepidium bidentatum Montin
Papau, Stoddart 2347 (US, CANTY, BISH).

LEGUMINOSAE

* Abrus precatorius L.
Rangiteia-Pata, Stoddart 2329 (US, CANTY); Aremati, Stoddart 2306 (US).

* Acacia farnesiana (L.) Willd.
O Arutanga, Stoddart 2304 (US, CANTY, BISH).

* Adenanthera pavonina L.
Vaipae, Stoddart 2330 (US).

* Alysicarpus vaginalis (L.) DC.
Rangiteia-Pata, Stoddart 2326 (US).

* Bauhinia monandra Kurz (?)
Vaipae, Stoddart 2337 (US, CANTY, BISH).

* Caesalpinia pulcherrima (L.) Sw.
Arutanga, Stoddart 2290 (US, CANTY, BISH).

+ Canavalia cathartica Thouars
Vaipae, Stoddart 2238 (US).

* Crotalaria pallida Ait.
Ootu, Stoddart 2183 (US, CANTY, BISH); Maungapu Hill, Stoddart 2277 (US, CANTY).

* Derris elliptica Benth.
Teaitu, Stoddart 2318 (US, CANTY).

* Delonix regia (Bojer) Raf.
Arutanga, Stoddart, sight; mentioned by Tamashiro (1964).

ø Erythrina variegata var. orientalis (L.) Merr.
Vaipeka, Stoddart 2339 (US, CANTY, BISH).

* Indigofera suffruticosa Mill.
Vaipae, Stoddart 2247 (US, CANTY, BISH).

ø Inocarpus fagifer (Park.) Fosb.
Teaitu, Stoddart 2317 (US, CANTY, BISH).

\+ Leucaena insularum (Lam.) Dän.
Ootu, Stoddart 2175 (US, CANTY), Stoddart 2203 (US, CANTY, BISH).

* Mimosa pudica L.
Ootu, Stoddart 2212 (US).

\+ Mucuna gigantea (Willd.) DC.
Arutanga, Stoddart 2303 (US, CANTY, BISH).

\+ Sophora tomentosa L.
Ootu, Stoddart 2185 (US, CANTY, BISH), Stoddart 2190 (US, CANTY).

\+ Vigna marina (Burm.) Merr.
Ootu, Stoddart 2184 (US, CANTY).

RUTACEAE

* Citrus sp.
Main island, Stoddart, sight.

SURIANACEAE

\+ Suriana maritima L.
Ootu, Stoddart 2204 (US, CANTY, BISH).

ANACARDIACEAE

* Mangifera indica L.
Vaipae, Stoddart 2229 (US, CANTY, BISH).

EUPHORBIACEAE

* Acalypha godseffiana Mast.
Arutanga, Stoddart 2288 (US, CANTY, BISH).

* Acalypha wilkesiana var. circinata M.-A.
Aretea, Stoddart 2310 (US, CANTY, BISH).

ø Aleurites moluccana (L.) Willd.
Vaipae, Stoddart 2239 (US, CANTY, BISH); Rangiteia-Pata, Stoddart 2323 (US).

\+ Euphorbia chamissonis (Kl. and Gke.) Boiss
Ootu, Stoddart 2200 (US, CANTY, BISH).

* Euphorbia hirta L.
Ootu, Stoddart 2211 (US); Maungapu Hill, Stoddart 2282 (US).

* Manihot esculenta Crantz
Arutea, Stoddart 2307 (US, CANTY, BISH).

RHAMNACEAE

+ Colubrina asiatica (L.) O.Ktze.
Ootu, Stoddart 2182 (US, CANTY, BISH).

TILIACEAE

+ Corchorus torresianus Gaud.
Ootu, Stoddart 2173 (US, CANTY, BISH).

+ Triumfetta procumbens Forst.
Ootu, Stoddart 2195 (US, CANTY, BISH).

* Triumfetta rhomboidea Jacq.
Vaipae, Stoddart 2243 (US, CANTY, BISH); Maungapu Hill, Stoddart 2278 (US, CANTY).

MALVACEAE

ø Hibiscus tiliaceus L.
Vaipae, Stoddart 2251 (US, CANTY); Teruarei, Stoddart 2260 (US).

* Hibiscus (ornamental hybrid)
Vaipae, Stoddart 2240 (US, CANTY, BISH).

* Sida rhombifolia L.
Akitua, Stoddart 2220 (US, CANTY); Vaipae, Stoddart 2234 (US, CANTY, BISH).

ø Thespesia populnea (L.) Sol. ex Correa
Rapota, Stoddart, sight.

BOMBACACEAE

* Ceiba pentandra (L.) Gaertn.
Arutanga, Stoddart 2291 (US).

GUTTIFERAE

+ Calophyllum inophyllum L.
Teruarei, Stoddart 2262 (US, CANTY, BISH).

CARICACEAE

* Carica papaya L.
Perekiatu, Stoddart 2286 (US, CANTY, BISH).

PASSIFLORACEAE

* Passiflora rubra L.
Vaipae, Stoddart 2244 (US, CANTY).

CUCURBITACEAE

* Cucurbita maxima Duch. (?)
Vaipae, Stoddart 2246 (US, CANTY, BISH).

* Luffa cylindrica (L.) Roem.
Teruarei, Stoddart 2259 (US, CANTY, BISH); Rangiteia-Pata, Stoddart 2322 (US, CANTY).

* Momordica charantia L.
Ootu, Stoddart 2199 (US, CANTY).

LYTHRACEAE

\+ Pemphis acidula Forst.
Ootu, Stoddart 2181 (US, CANTY, BISH).

LECYTHIDACEAE

\+ Barringtonia asiatica (L.) Kurz
Aretea, Stoddart 2308 (US, CANTY, BISH).

MYRTACEAE

* Eugenia uniflora L.
Aretea, Stoddart 2309 (US, CANTY, BISH).

* Eugenia jambos L.
Aretea, Stoddart 2311 (US, CANTY, BISH).

ONAGRACEAE

ø Ludwigia octovalvis (Jacq.) Raven
Vaipae, Stoddart 2250 (US, CANTY, BISH).

OLEACEAE

* Jasminum officinale var. grandiflorum (L.) Kobuski
Vaipae, Stoddart 2254 (US, CANTY, BISH).

APOCYNACEAE

* Allamanda cathartica L.
Vaipae, Stoddart 2299 (US).

* Catharanthus roseus (L.) G. Don
Vaipae, Stoddart 2253 (US, CANTY, BISH).

* Nerium oleander var. indicum (Mill.) Deg. and Greenw.
Arutanga, Stoddart 2302 (US, CANTY).

* Tabernaemontana divaricata (L.) R.Br.
Vaipae, Stoddart 2257 (US, CANTY, BISH).

CONVOLVULACEAE

ø Ipomoea batatas (L.) Lam.
Main island, Stoddart, sight.

+ Ipomoea indica (Burm.) Merr.
Vaipeka, Stoddart 2338 (US, CANTY, BISH).

+ Ipomoea littoralis BL. (?)
Arematі, Stoddart 2305 (US, CANTY, BISH).

+ Ipomoea macrantha R. and S.
Ootu, Stoddart 2188 (US); Akitua, Stoddart 2224 (US, CANTY, BISH).

+ Ipomoea pes-caprae subsp. brasiliensis (L.) Ooststr.
Ootu, Stoddart 2208 (US, CANTY, BISH).

BORAGINACEAE

+ Cordia subcordata Lam.
Akitua, Stoddart 2219 (US, CANTY, BISH).

+ Heliotropium anomalum H. and A.
Ootu, Stoddart 2213 (US, CANTY, BISH).

+ Tournefortia argentea L.f.
Ootu, Stoddart 2214 (US).

VERBENACEAE

* Clerodendrum speciosissimum Van Geert
Vaipae, Stoddart 2256 (US, CANTY, BISH).

* Stachytarpheta urticifolia Sims
Vaipae, Stoddart 2236 (US, CANTY, BISH).

LABIATAE

* Coleus scutellarioides L.
Rangiteia-Pata, Stoddart 2324 (US, CANTY).

* Leonurus sibiricus L.
Aretea, Stoddart 2313 (US, CANTY, BISH).

* Ocimum suave Willd.
Vaipae, Stoddart 2258 (US, CANTY, BISH); Maungapu Hill, Stoddart 2293 (US, CANTY, BISH).

* Salvia occidentalis L.
Vaipae, Stoddart 2233 (US, CANTY, BISH); Maungapu Hill, Stoddart 2284 (US).

SOLANACEAE

* Capsicum frutescens L.
Vaipae, Stoddart 2248 (US, CANTY, BISH).

* Datura metel L.
Ootu, Stoddart 2207 (US); Arutanga, Stoddart 2287 (US, CANTY, BISH).

* Solanum lycopersicum L.
Vaipae, Stoddart 2228 (US).

ø Solanum nigrum var. americanum (Mill.) O.E.Sch.
Ootu, Stoddart 2198 (US, CANTY, BISH); Vaipae, Stoddart 2249 (US, CANTY, BISH).

SCROPHULARIACEAE

\+ Lindernia crustacea (L.) F.Muell. (?)
Rangiteia-Pata, Stoddart 2327 (US).

BIGNONIACEAE

* Spathodea campanulata Beauv.
Anaunga, Stoddart 2268 (US, CANTY, BISH).

RUBIACEAE

\+ Guettarda speciosa L.
Ootu, Stoddart 2189 (US, CANTY, BISH).

ø Morinda citrifolia L.
Ootu, Stoddart 2206 (US, CANTY, BISH).

* Spermacoce suffrutescens Jacq.
Ootu, Stoddart 2201 (US, CANTY).

\+ Timonius polygama (Forst.) Rob.
Ootu, Stoddart 2176 (US, CANTY, BISH); Akitua, Stoddart 2221 (US, CANTY, BISH); Tavaerua Iti, Stoddart 2344 (US, CANTY).

CAMPANULACEAE

* Hippobroma longiflora (L.) G.Don
Main island, south point, Stoddart 2263 (US, CANTY, BISH

GOODENIACEAE

\+ Scaevola taccada var. tuamotuensis St J.
Ootu, Stoddart 2186 (US, CANTY, BISH).

COMPOSITAE

* Ageratum conyzoides L.
Vaipae, Stoddart 2231 (US, CANTY); Maungapu Hill, Stoddart 2294 (US, CANTY, BISH).

* Bidens pilosa L.
Ootu, Stoddart 2202 (US, CANTY, BISH); Vaipae, Stoddart 2232 (US, CANTY); Maungapu Hill, Stoddart 2281 (US, CANTY).

* Eclipta prostrata (L.) Hassls.
Rangiteia-Pata, Stoddart 2328 (US, CANTY, BISH).

ø Emilia sonchifolia (L.) DC.
Ootu, Stoddart 2194 (US, CANTY); Vaipae, Stoddart 2252 (US, CANTY, BISH); Maungapu Hill, Stoddart 2279 (US, CANTY, BISH).

* Gaillardia pulchella var. picta (Sweet) Gray
Ootu, Stoddart 2205 (US, CANTY, BISH), Stoddart 2209 (US, CANTY, BISH).

* Sonchus oleraceus L.
Ootu, Stoddart 2197 (US, CANTY, BISH).

* Tagetes erecta L.
Vaipae, Stoddart 2301 (US, CANTY).

* Tagetes patula L. (?)
Vaipae, Stoddart 2300 (US).

* Tithonia diversifolia (Hemsl.) A. Gray
Vaipae, Stoddart 2237 (US, CANTY, BISH).

* Vernonia cinerea (L.) Less.
Maungapu Hill, Stoddart 2280 (US).

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ADDENDUM

The specimens *Stoddart 2264* and *2283*, referred on pages 74, 117 and 122 to *Sporobolus africanus* are in all probability *Sporobolus fertilis* (Steud.) Clayton, though the species in the *S. indicus* complex are extremely difficult to distinguish satisfactorily. - F.R.F.

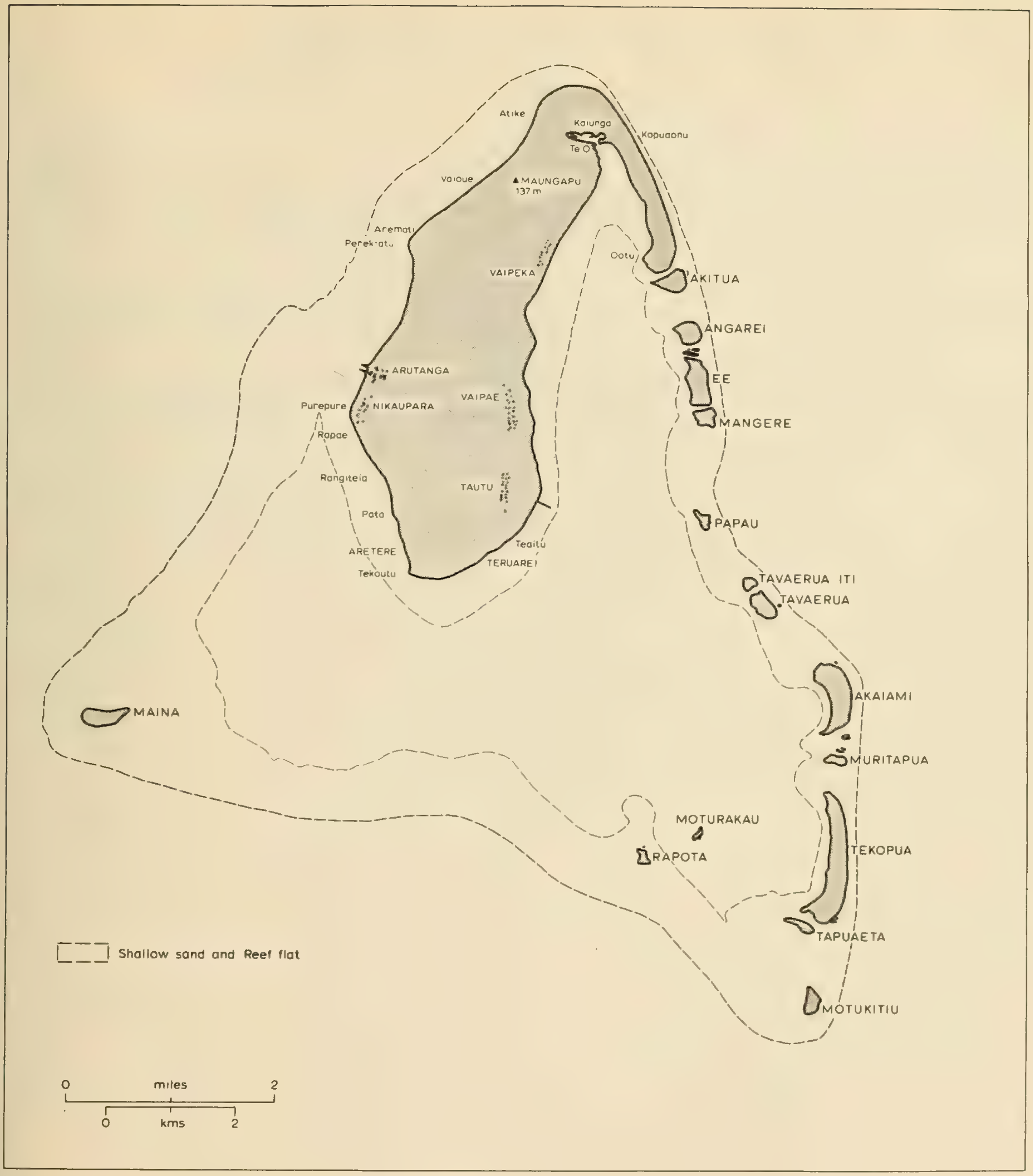

Figure 32. Aitutaki plants: collecting localities

5. BRYOPHYTES FROM THE COOK ISLANDS

C.C. Townsend

Calymperes tenerum C.M.
Aitutaki: Maungapu Hill, Stoddart 2296 (K); Teruarei, Stoddart 2336 (K).

Calymperes volkensii Broth.
Rarotonga: Oneroa, Stoddart 2101 (K).

Brachymenium indicum (Doz. and Molle.) Bosch and Lac.
Aitutaki: Akitua, Stoddart 2216 (K); Te O, Stoddart 2271 (sterile, probably this species) (K).

Ectropothecium sp.
Rarotonga: Oneroa, Stoddart 2102 (K).

6. VEGETATION AND FLORISTICS OF THE AITUTAKI MOTUS

D.R. Stoddart

The vegetation of the Aitutaki reef islands is of interest for several reasons. First, Aitutaki is remotely located in the central Pacific on a diversity gradient extending from the densely vegetated and floristically diverse atolls of the Carolines and southern Marshalls to isolated and depauperate islands such as Clipperton. The gradient effects should be apparent at Aitutaki in the absence of species restricted to the western Pacific (notably the mangroves and the seagrasses, but also many species of broadleaf trees). Second, the comparatively low floristic diversity will mean that certain species will be more important components of the vegetation than they are elsewhere. This is the case with shrubs such as *Timonius polygama*, abundant at Aitutaki and at Mopelia and throughout the Tuamotus to Henderson Island; and with *Euphorbia chamissonis*, though this has a wider distribution. Third, the unusual geomorphology of the motus, with stormswept seaward gravel spreads and conglomerate platforms and relatively small sand areas, should influence the type and distribution of the vegetation units present. And fourth, the range of size of the motus should have implications for the MacArthur and Wilson theory of island biogeography; the presence of a high island immediately adjacent to the motus adds a further factor to the analysis of area, distance and ecological diversity.

In this paper, we first consider the floristics of the motus, in terms both of biogeography and of island size and floristic diversity, and then discuss the vegetation units, emphasizing the place of Aitutaki in general Pacific distribution patterns, and noting the absence of certain widespread types which might have been expected in this location. The discussion covers only the vascular plants listed in the accompanying paper by F.R. Fosberg, and does not extend to either marine algae or to terrestrial algae, fungi, lichens, liverworts and mosses.

FLORISTICS OF THE MOTUS

Size of the flora

During the 1969 Expedition 72 numbers of plants (including 3 mosses and lichens) were collected on the Rarotonga reef islands, and 183 (including 14 mosses, liverworts, fungi, lichens and blue-green algae) at Aitutaki. The Rarotonga vascular plants are reported by Fosberg in Stoddart and Fosberg (1972), those from Aitutaki by Fosberg in this Bulletin.

Of the total of ca 140 species recorded at Aitutaki, 80 or 57 per cent are only found on the main island and not on the motus. 62 species are recorded from the smaller islands, including the Ootu peninsula. Excluding the volcanic islets of Rapota and Moturakau and also the much-disturbed Ootu peninsula, the number of species recorded from the motus is 45 (32 per cent). This compares with 41 species from the three Rarotonga reef islands. Only 26 species are common to the two lists, however: 19 Aitutaki motu species are missing from the Rarotonga islands, and 15 Rarotonga species are not recorded from the Aitutaki islands. Some of the missing species, where they do occur, are extremely common; their absence is further discussed below.

The 45 Aitutaki motu species comprise a flora comparable in size with that of other central and east Pacific atolls (Table 11). At least 50 per cent of the species can be considered indigenous, and this indigenous flora is intermediate in size between those of remote, small or dry islands such as Clipperton, Vostok and Flint, and large, wet or more accessible atolls such as Jaluit, Arno, Kapingamarangi and Onotoa. The number of species is similar to that for atolls in the Society and Tuamotu Islands: the nearest atoll for which a comparable list is available is Mopelia in the Societies (Sachet, in litt.).

Composition of the flora

The Cook Islands, by their remote location in the central Pacific, lack many species common on west Pacific atolls the ranges of which terminate in Tonga, Fiji or Samoa. Van Balgooy (1960, p.410) has clearly shown the magnitude of the floristic demarcation between Tonga and the Cooks when considering the total floras of these groups: in Tonga 104 genera are of 'western' affinity (Palaeotropical, Malaysian-Australian, Australian) compared with 41 such genera in the Cooks. Philipson (1971) has reinforced this conclusion with an analysis of the affinities of the woody species of Rarotonga, though clearly Pacific and pan-tropical components are more important in the strand flora.

15 tree species have been recorded from the Aitutaki islands, 4 of them only from the volcanic islets. Only 8 species are common: Cocos, Guettarda, Pandanus, Morinda, Casuarina, Hernandia, Leucaena and Pisonia. Hibiscus is widely distributed but rare, in sharp contrast to its abundance on the main island. The rarity of three species (Calophyllum inophyllum, Cordia subcordata, Thespesia populnea) is striking when compared with their wide distribution and abundance on other Pacific islands. Thus Thespesia, important on atolls such as Kapingamarangi, forms trees 20 m tall as close to Aitutaki as Penrhyn and Manihiki in the northern Cooks (Linton, 1933). Both Pandanus and Cordia are also absent from the reef islands of Rarotonga. Other common western Pacific atoll

species which are absent from the reef islands are:

Allophylus timorensis Common on Arno and Kapingamarangi, forms a major woodland type in the southern Marshalls.
Barringtonia asiatica Present on mainland Rarotonga and Aitutaki, and on the Aitutaki volcanic islets.
Intsia bijuga Common on Arno and other Marshalls atolls; reaches its eastern limit in Tonga and Samoa (Yuncker, 1959).
Neiosperma oppositifolia Important woodland type in the Marshalls and extends to the Line Islands; absent in the Tokelaus.
Premna obtusifolia Common in western Pacific atolls and high islands eastward to Marquesas and Henderson.
Soulamea amara Common at Kapingamarangi and in most western Pacific atolls.

Of particular significance is the absence of mangroves from the Cook Islands. Six species in the genera *Rhizophora*, *Bruguiera*, *Lumnitzera* and *Xylocarpus* are recorded from Tonga (Yuncker, 1959) and three from Samoa in the genera *Rhizophora*, *Bruguiera* and *Xylocarpus* (Setchell, 1924). They are also absent from the Society Islands and the Tuamotus and other eastern and northern Pacific atolls, including the Tokelaus (though introduced in Hawaii and Tahiti). Their absence indicates an important vegetational and sedimentary difference between the Cooks and the islands of the west Pacific.

14 species of shrubs are present on the Aitutaki islets, 3 being uncommon recent introductions and the rest widespread and mostly abundant. Some of these shrubs are geographically extensive (*Pemphis*, *Suriana*, *Tournefortia*, *Sophora*, *Scaevola*), others are regionally restricted (*Timonius polygama*). Some are inexplicably absent from the Rarotonga reef islands though present and indeed abundant at Aitutaki: these include *Pemphis*, *Timonius*, *Pipturus* and *Corchorus torresianus*. Absent from both the Rarotonga and Aitutaki islands are *Euphorbia atoto* (common on Rangiroa and Raroia in the Tuamotus but here replaced by *E. chamissonis*) and *Pluchea carolinensis* (extensive, though recently introduced, in low scrub at Christmas Island).

At least 34 species of herbs are recorded from the Aitutaki motus, with an additional 13 from the Rarotonga reef islands. Of these only 10 are common: *Stenotaphrum micranthum* (exotic), *Fimbristylis cymosa*, *Heliotropium anomalum*, *Polypodium scolopendria*, *Triumfetta procumbens*, *Cassytha filiformis*, *Vigna marina* and *Tacca leontopetaloides* (exotic) are found on most motus. There are curious differences between the Rarotonga and Aitutaki lists. Thus *Sesuvium portulacastrum*, present on Rarotonga, is absent not only from the motus but also from the main island of Aitutaki, in spite of its wide distribution

through the Line Islands and its importance as a vegetation type at Christmas Island (Christophersen, 1927; Jenkin and Foale, 1968). Other species present on Rarotonga but not the Aitutaki islands include Asplenium nidus, Davallia solida, Thuarea involuta, Peperomia species, Portulaca lutea, Canavalia sericea, Stachytarpheta urticifolia (exotic), Vitex trifolia, Sonchus oleraceus (exotic) and Wedelia biflora.

Particularly interesting is the absence, with the mangroves, of the sea grasses. Species of Syringodium, Diplanthera (=Halodule), and Halophila are recorded from Tonga by Yuncker (1959), but there are no records from the Cooks. Halophila is present in Samoa (Setchell, 1924), Tahiti and Hawaii and may be more widely distributed in the central Pacific than the other sea grasses, but it was not seen in the Cooks in 1969. The absence of this group, as with the mangroves, has important sedimentological implications: in consequence Aitutaki and the other Cook atolls more closely resemble the Tuamotus than the reefs of the western Pacific.

Species numbers on the motus

Table 12 gives the area and total numbers of species of vascular plants, classified as trees, shrubs and herbs, for each of the Aitutaki motus, together with the volcanic islets of Moturakau and Rapota and the Ootu peninsula. Data for the three reef islands of Rarotonga which are appended (from Stoddart and Fosberg, 1972) show similar values to those of Aitutaki. The motus have individual floras of 16-25 species each; the largest islands, Tekopua and Akaiami, have 25 and 22 species respectively. The only island to diverge markedly from the general pattern is the small sand cay south of Tapuaeta, with 5 species, while Ootu, a peninsula not a motu, much disturbed by man, has 42 species.

These data are of interest by comparison with those for the islets of Kapingamarangi Atoll, Caroline Islands, determined by Niering (1956). The Kapingamarangi data indicated a constant number of species per island for islands less than 1.4 ha (3.5 acre) in area, with a rapid rise in species numbers with increasing island area above this size. Wiens (1962) suggested that the threshold size is related to the smallest area of land which can support a permanent freshwater lens. The Kapingamarangi data were subsequently used by MacArthur and Wilson (1963; 1967, pp.30-32) in their theory of island biogeography relating the equilibrium level of an island biota to distance from source area (controlling immigration rate) and island size (controlling extinction rate).

The Aitutaki data raise two significant issues concerning the MacArthur and Wilson model and the Kapingamarangi data. First, can a similar control of number of species by island size be demonstrated for Aitutaki, where all except one of the islands lies above the 1.4 ha threshold (Aitutaki and Kapin-

gamarangi have approximately the same annual rainfall of 2000 mm/yr), and where the largest Aitutaki motu is twice as large as Kapingamarangi's? MacArthur and Wilson's theory in fact predicts that the species-area relationship will be more marked in distant islands such as Aitutaki than in near islands such as Kapingamarangi, assuming that the source region in both cases is in the western Pacific. Second, whether or not this relationship exists, what is the effect of the existence of a 'species-reservoir' on the main volcanic island of Aitutaki, with between 4 and 9 times as many species as on individual motus, less than 8 km distant from the farthest of them?

Tables 13-15 document the distribution of trees, shrubs and herbs on the Aitutaki motus, volcanic islets and Ootu peninsula. The tables are based on sight records supplemented by collections made during the surveying of the islands. It is probable that some grasses have been systematically unrecognised in the field, but the other groups are thought to be reasonably complete. It should be noted that these tables are not directly comparable with those of Niering (1956), who classifies Tournefortia and Pemphis as trees and Euphorbia chamissonis as a herb; trees of Tournefortia are found at Aitutaki but this species is usually, and Pemphis is always, a shrub at Aitutaki, and Euphorbia too seems more appropriately termed a dwarf shrub than a herb. Figures 33 and 34, however, show direct comparisons, using Niering's classification, of the Aitutaki and Kapingamarangi data, in terms of numbers of species of trees, shrubs and herbs, and total numbers of species, against island area, and also in terms of the proportion of the number of species in each class for all islands.

It is clear that the close association between species number and island area for the Kapingamarangi islands does not exist on Aitutaki. There is a slight positive relationship between number of species and log area over the size range 4-71 ha but the scatter of points is considerable, and the mean number of species per island (21.1) over this size range is close to that for both small and large islands. There is reasonable agreement between the Kapingamarangi and Aitutaki data for small islands (approximately 27 and 21 species per island at 4 ha) but marked divergence at larger island sizes, with the largest Kapingamarangi islands having 2-3 times as many species as Aitutaki islands of equivalent size. Note that 16 (50 per cent) of the Kapingamarangi islands are smaller than 1 ha in area, compared with 1 at Aitutaki; the species number for this latter (5) is rather low by comparison with Kapingamarangi islands of the same size. It is evident, then, that the influence of island area is masked at Aitutaki when considering total numbers of species.

The influence of size for the two groups of islands can also be compared for the groups of trees, shrubs and herbs. At Kapingamarangi the number of tree species increases over the size range 0.16-32 ha from 5 to 17; while at Aitutaki, ignoring

the smallest islet, the number is relatively invariant at about 7.5 species over the range 3.8-71 ha. At Kapingamarangi the number of shrub species is fairly constant at 1-3 up to 2 ha and then increases slightly to 5 species or more; at Aitutaki the number is variable but averages about 4 species over the size range. The most spectacular increase in species number with area is seen with herbs at Kapingamarangi: from 2.5 on islands of 1 ha to more than 20 (on one island 35) on islands larger than 10 ha. In this case it is clear that the diversity of the herb flora makes a major contribution to the general curve for all species derived by Niering. At Aitutaki, on the other hand, there is only a weak trend, from rather less than 10 to rather more than 10 species per island in the range 3.8-71 ha.

These differences in trend between groups of plants mean that the floras of large islands have a different composition from those of small ones on Kapingamarangi, but this is not the case on Aitutaki. Figure 2, plotting trees, shrubs and herbs as a percentage of the total flora for each island shows that on Kapingamarangi the proportion of trees decreases from about 80 to about 40 per cent with increasing island size; shrubs remain constant at about 20 per cent; and herbs increase from about 10 to about 60 per cent. On Aitutaki trees are fairly constant at 35 per cent, shrubs at 20 per cent, and herbs at 45 per cent.

In interpreting the species-area relationship, therefore, we need to consider not only the total size but also the composition of the island floras. Consider a series of islets on an atoll or almost-atoll such as Kapingamarangi or Aitutaki. The smallest islets will normally support a strand flora of grasses, sedges, vines and other herbs, with beach-crest shrubs and in some cases trees. The plants capable of surviving in such environments are limited in number and many are of pantropical or at least Indo-Pacific distribution. On large inhabited islands much of the area will have been cleared during the last few centuries for coconut plantations. This will have had the following effects. (1) The number of tree species will have been reduced on larger islands with the eradication of certain vegetation types. This is illustrated by the disappearance of <u>Barringtonia</u>, <u>Calophyllum</u>, <u>Pisonia</u> and <u>Cordia</u> from many islands. (2) The number of shrub species will probably remain the same, partly because there is probably an upper limit to the number of such species which can be successfully established on such islands, even if artificially introduced, but also because the native shrubs of beach crest, gravel spread and conglomerate platform areas are unlikely to be cleared for economic reasons and survive even on islands severely disturbed by man. (3) With the establishment of plantations and increasing human activity the number of herb species, especially widespread weedy species, will increase, as a result both of deliberate and inadvertent introduction and also because clearing prepares substrates for colonisation and reduces competition from already established species; the effect will be greater on larger islands.

This explanatory scheme is consonant with the Kapingamarangi data, and it perhaps needs to be stressed that on many Pacific atolls we are no longer dealing simply with patterns resulting from natural immigration and extinction, but with vegetation actively managed by man: or, as Hatheway (1953, 6) put it for Arno Atoll, with people and plants rather than flora and habitat.

Does the scheme apply to the Aitutaki motus? Large areas on the bigger motus are covered with coconut woodland, now the most extensive woodland vegetation. There is little doubt that Pisonia - and perhaps other species such as Cordia and Hibiscus - were formerly more extensive. With their removal from some islands a reduction in tree species diversity can be inferred. The number and identity of shrub species is monotonously regular on all the islands: large areas covered with Pemphis and Suriana, and smaller contributions by Tournefortia, Scaevola, Sophora, Euphorbia, Timonius and Corchorus. However, unlike the situation on Kapingamarangi, the herb flora (including weeds) does not markedly increase on the larger islands, in spite of their clearance for coconuts: there is no doubt that a major reason why there is no simple increase in total size of flora with island size on Aitutaki is because the herb component is relatively invariant with size.

Why is this so? If Aitutaki were an atoll, situated in the central Pacific, then it could be argued that immigration was reduced because of the distance from source areas to the west, in Tonga and Fiji. To some extent such an explanation must partially account for the smaller floras of the Cooks, the Tuamotus and other central and east Pacific atolls compared with the Carolines and the Marshalls. But there is at Aitutaki a reservoir of weedy species on the main volcanic island immediately adjacent to the motus. Many species, not only weeds, which are elsewhere common on atoll islands, are widespread on this volcanic island but are absent from the motus. They include ferns (Nephrolepis hirsutula), grasses (Dactyloctenium aegyptium and several others), sedges (several Cyperus species), Portulaca oleracea, Abrus precatorius, Canavalia cathartica, Caesalpinia, Euphorbia hirta, Barringtonia asiatica, Ipomoea littoralis, Stachytarpheta urticifolia, Spermacoce suffrutescens, and Vernonia cinerea. Making allowance for the fact that some motu species may have been overlooked (and this is particularly true of sterile grasses such as Lepturus and Paspalum, it is astonishing that many of these species have not established themselves on the islands. The presence of some of them, such as Calophyllum and Abrus, on the volcanic islets in the south suggests the operation of an ecological control.

The list would be longer if it included certain species recorded from the motus but which cannot be said to have established themselves. Akitua, which can be reached on foot from

the mainland at Ootu, has three herb species (Bidens pilosa, Emilia sonchifolia, Boerhavia repens) not otherwise recorded from the motus, plus, where the path from Ootu reaches the beach, a patch of Cenchrus echinatus. Cenchrus is also recorded at the landing stage on Tekopua, but on no other motu; yet it is common on the mainland and on the Ootu peninsula.

Thus whatever limits the establishment of these species on the motus, it is not lack of colonising material from the Aitutaki "reservoir", and it has nothing to do with isolation in the central Pacific. It seems rather that the present vegetation of the islands has some property or character which inhibits the colonisation, establishment and spread of new species, even of weeds in coconut plantations. This has been noted before, for example in the case of the localisation of weeds such as Mimosa pudica near the landing stage at Diego Garcia Atoll, an intensively managed coconut plantation (Stoddart, 1971, 141), and similar observations have been made by Bayliss Smith (in preparation) at Ontong Java Atoll and by Parham (1971, p.593) in the Tokelau Islands. The processes of colonization by sea- and wind-transported propagules are certainly continuing and important on reef islands, and recent work on the British Honduras cays has shown that extinction and floristic change is more widespread than hitherto suspected, even over short periods of years and in the absence of catastrophic storms, but it nevertheless appears unlikely that these processes account for the present levels of species numbers on the Aitutaki motus, and doubtful that their operation as envisaged by MacArthur and Wilson gives a sufficient explanation of species numbers on the Kapingamarangi islands.

Niering's Kapingamarangi data have recently been re-analysed by Whitehead and Jones (1969). Their analysis, which breaks down the total species numbers into groups of recent introductions, strand species, and non-strand species, is particularly apposite to this discussion. They argue that on small islands, lacking a freshwater lens (i.e. less than 1.5 ha), the flora consists only of salt-tolerant strand species, limited in number by the size of the available "species pool" in this category and hence not greatly affected by island area. They also found that there are no recent introductions on islands of less than 1.6 ha in area. As a result, smaller islands have 7-8 species each and larger islands 12-14. Above the freshwater lens threshold, however, there is a rapid increase in the number of non-strand, salt-intolerant species, with numbers closely related to island area. It is these species, they argue, which control the overall species-area relationship found by Niering. Whitehead and Jones (1969, p.176) suggest that most of the species in both strand and non-strand categories are drift-dispersed. Unfortunately they do not list the species placed by them in each category, apart from the coconut, which they classify (mis-classify?) as a strand species. By implication, however, they regard the dispersal of the non-strand species as a natural phenomenon. They

do not consider the effect of human activities on species numbers, other than in terms of recent introductions. Hence, while clarifying some aspects of the MacArthur and Wilson analysis of the Kapingamarangi data, they do not make it possible to explain in terms of their model the divergent situations at Kapingamarangi and at Aitutaki.

The presence of the volcanic island at Aitutaki affects the floras of the motus other than by serving as a reservoir of weeds and other plants from which they may be colonised. The inhabitants can utilise the fertile volcanic soils rather than cultivate the carbonate sands of the motus. Breadfruit and taro, of common atoll crops, are unknown on the motus; the Polynesian Chestnut *Inocarpus fagiferus* is only found on the main island, as are *Citrus* species, *Persea americana*, *Musa* species, *Sorghum*, *Capsicum*, *Solanum* species, and other food crops; useful trees such as *Ceiba pentandra* are similarly distributed, as are decoratives such as *Crinum*, *Canna*, *Catharanthus*, *Gloriosa superba*, *Tagetes*, and many others. *Carica papaya* is found on the motus only on Akitua, although common on the main island. In effect, therefore, although heavily affected by human activities, the motus are islands lacking human populations, settlements and cultivation. Apart from coconuts the only food plant on the motus is the Polynesian Arrowroot *Tacca leontopetaloides*, which is rather uncommon on the main island. Had there been settlements on the motus, especially on the larger islands of Akaiami and Tekopua, many of these species would have been locally introduced and cultivated and the species numbers would have approached closer to those of Kapingamarangi islands of equivalent size. It would be interesting to test this inference by comparison with inhabited true atolls in the Cook Islands, such as Manihiki, Penrhyn and Palmerston, and with an uninhabited atoll such as Suwarrow. Similarly the Aitutaki patterns should resemble those of other reef-encircled high islands such as Bora-Bora.

VEGETATION OF THE MOTUS

The following accounts of the main vegetation units, arranged by scrub types, woodland types, and herb types, are derived from the surveys and descriptions of the individual islands previously described. The vegetation units recognised follow those of Fosberg (1953, in press). Particular attention is given to the geographical relationships of the units described. This discussion is followed by brief notes on vegetation units absent from the Aitutaki motus though important on other Pacific atolls.

Pemphis Scrub (Plates 28 and 29)

Pemphis acidula commonly forms a narrow zone of scrub on the seaward sides of motus, varying in width from 10 m at Papau, 25-30 m on Ee, Mangere and Tavaerua Iti, 40 m at Motu-

kitiu, to 50 m at Akitua, Angarei, Tavaerua and Muritapua. The scrub consists of shrubs up to 2 m tall, often wind-sheared and aligned in windrows oriented slightly north of west. Pemphis is the characteristic outpost species on the surface of the conglomerate platform. The shrubs are openly branched and lack the height and density of Pemphis scrub on some other atolls such as Aldabra. On islands where the conglomerate platform is much reduced and the seaward coast is formed by a sand and gravel ridge, Pemphis is rare (Tekopua, Akaiami). It is also poorly developed on the seaward side of Papau, possibly because it has been destroyed by rapid beach retreat. On lagoon shores, mainly on sand, Pemphis often forms a narrow belt, often of taller shrubs (e.g. on Ee, Mangere, Angarei, Akitua, Muritapua); in many cases these beaches are slightly retreating and the roots of the Pemphis are exposed to seawater. Wiens (1959) and others have drawn attention to the common association of Pemphis with low rocky substrates, often without soil and subject to salt-water flooding and salt spray.

Pemphis scrub in such situations, on exposed rocky substrates, either of reef-rock (feo) or island conglomerates, is found throughout the Societies and Tuamotus, from Mopelia to Rangiroa, Raroia and Mururoa (Sachet, in litt.; Stoddart and Sachet, 1969; Doty, 1954; Chevalier et al., 1968). In many of the Tuamotu atolls, however, it is more common along channels between islands (hoa) than on seaward coasts, which are generally formed by high sand and gravel ridges rather than by wide horizontal conglomerate platforms. As a result Pemphis is probably less abundant as a vegetation type than on Aitutaki. Pemphis is also found on exposed rocky substrates in the Tokelaus (Parham, 1971) and at Funafuti (Hedley, 1896). In the Gilberts Moul (1957) reports it as a rampart scrub rather than on rocky substrates. In general it appears common in the southern and southeastern Polynesian atolls, though not recorded from some more remote locations such as Oeno (St John and Philipson, 1960). It is widely distributed in the northwest Pacific, but is not recorded from Kapingamarangi. It is widespread and extensive in the central and western Indian Ocean, though absent from Diego Garcia in the Chagos Archipelago. In spite of this wide distribution, it is remarkably absent from the central equatorial and central north Pacific islands: it is not recorded from Hawaii and the other Phoenix Islands*, Caroline, Flint, Vostok, Palmyra, Christmas, Washington, Fanning, Baker and Jarvis islands. Its absence from Christmas is especially noteworthy because of the large areas of terrain covered by similar low scrub communities (Jenkin and Foale, 1968). Pemphis extends through the northern Cooks at least to Penrhyn and Manihiki, where it reaches heights of 6-7 m (Linton, 1933), and the reasons for its absence further north are not known.

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*Since this Bulletin was submitted, F.R. Fosberg and the writer found extensive stands of Pemphis on Hull Atoll, Phoenix Islands and a single individual on Canton. We have since found that Pemphis was collected by J.T. Arundel on Hull and was cited by Hemsley (1884), p.116.

In the Polynesian area Pemphis generally forms shrubs rather than trees, though a large tree is reported from Henderson (St John and Philipson, 1962) and trees are common in the Melanesian area and Marshall Islands.

The occurrence of Pemphis is thus subject to a primary biogeographic control, and to a secondary substrate and exposure control.

Suriana Scrub

Suriana maritima forms a scrub 1-2 m tall, in places reaching 2-3 m and exceptionally 4 m, on the seaward sides of islands, usually inland of the Pemphis zone. The scrub is open, with individual plants 1-2 m apart. It generally covers thin sand and gravel sheets, in contrast to the rocky substrates occupied by Pemphis. The area occupied by Suriana on Aitutaki islands appears to be dependent on the extent of such low-lying sand and gravel sheets. The width of the zone varies from 50-75 m on Akitua, Papau, Tavaerua Iti, Taverua, Muritapua and Tekkopua; 95 m on Motukitiu; 125-130 m on Angarei and Mangere; to a maximum of 50-430 m on Ee. On Tekopua, where Pemphis is weakly developed, Suriana forms a narrow fringe on the seaward beach crest, occupying a very different situation from that on other motus. Similarly on Akaiami, where a seaward gravel spread is also lacking, Suriana forms a narrow fringe on the seaward beach ridge. Ground cover beneath the scrub is sparse. In more exposed areas it is limited to Heliotropium anomalum and Cassytha filiformis with seedling Tournefortia argentea and Suriana. In more inland areas Fimbristylis, Triumfetta procumbens, Ipomoea macrantha and Euphorbia chamissonis are present. Few other shrub species are represented; in inland sites they include Colubrina asiatica and Scaevola taccada (e.g. on Ee and Papau) and to seaward Tournefortia argentea. There is little admixture with Pemphis, though since Suriana stands are often surrounded on their seaward sides by a fringe of Pemphis the area of the latter may appear larger than it actually is. The two species, physiognomically so similar, can be readily distinguished from a distance by the yellow-green colour of Suriana foliage and the blue-grey green of Pemphis.

Suriana scrub occurs in a very different situation on Maina. Here it forms an open scrub 1.5-2 m tall in the interior of a sand cay. The scrub includes Tournefortia shrubs to 2 m tall and some Scaevola taccada, and a patchy ground cover of Cassytha, Triumfetta and Euphorbia chamissonis.

Suriana maritima is pan-tropical in distribution, but usually occupies a rather different situation to that on the Aitutaki motus. It is frequently extensive on lagoonal mudflats, as at Canton and Christmas in the central Pacific (Hatheway, 1955; Jenkin and Foale, 1968), but is rare on the seaward sides of islands. At Canton it is also found "in slab areas and less often in sandy areas swept by waves during violent storms"

(Degener and Gillaspy, 1955), and both here and at Christmas it occupies areas elsewhere characterised by Pemphis acidula. At Raroia, Tuamotus, where it occurs outside the Pemphis zone, Suriana extends out onto the conglomerate platforms and bare beach rock, situations normally occupied by Pemphis (Doty, 1954, p.33; Doty and Morrison, 1954, p.16). Suriana may also form a rampart scrub on seaward beach ridges, as on Akaiami and Tekopua at Aitutaki. Similarly at Rangiroa, Tuamotus, it forms a beach-crest hedge on seaward shores in the absence of Scaevola (Stoddart and Sachet, 1969, p.28), and it is also so distributed on Caroline Atoll (Clapp and Sibley, 1971). Finally it also forms extensive inland stands on sand cays, as at Maina, and is thus described from Alacran, Gulf of Mexico (Fosberg, 1962), and from Christmas Island.

In spite of its wide geographic distribution, Suriana is, like Pemphis, curiously unrecorded from a number of islands, while on others it is rare and fails to form distinctive vegetation units. It is not recorded, for example, from the Tokelaus (Parham, 1971), nor from Fanning, Jarvis, Washington and Baker islands (Christopherson, 1927), nor from Palmyra (Dawson, 1959), though it is common throughout the Australs and the Tuamotus (Brown, 1931). It is present but not common on Onotoa in the Gilberts (Moul, 1957) and present but rare at Jaluit in the Marshalls (Fosberg and Sachet, 1962) though common on other Marshall atolls, e.g. Likiep. Closer to Aitutaki, where it is so extensive, it is almost non-existent on the sand cays and absent from the mainland coast of Rarotonga; one single plant was seen there in 1969 (Stoddart and Fosberg, 1972). These differences suggest that further studies of the ecology of Suriana would be of interest. Fosberg (1974) notes that the species is tolerant of salt spray (though it is often seen dead in very exposed situations, presumably killed by salt-laden wind: Stoddart, 1971, pl. 35 for an example from Diego Garcia); substrate conditions are probably also of importance.

Scaevola scrub (Plate 27)

Scaevola taccada forms three distinct vegetation types at Aitutaki: a narrow beach-crest scrub on exposed shores; an extensive more open scrub on sand flats; and an open scrub under coconut woodland.

At Aitutaki the beach-crest Scaevola hedges are rare, simply because of the absence of seaward beach ridges: such hedges are found on Tekopua and Akaiami, the only islands with well-developed seaward ridges. On nearby Rarotonga, the Scaevola hedge is common and extensive, up to 4 m tall, on seaward beaches of reef islands, both alone and with Tournefortia argentea (Stoddart, 1972). Elsewhere in the Indo-Pacific Scaevola is characteristic of such situations, often forming a scrub 3-5 m tall, as for example at Diego Garcia (Stoddart, 1971); in the Marshalls (Taylor, 1950; Hatheway, 1953; Fosberg and Sachet, 1962); the Gilberts (Moul, 1957); the Ellice Islands

(Hedley, 1896); and the Tokelaus (Parham, 1971). It appears to be less common through the Tuamotus, being not primarily a beach species at Raroia (Doty and Morrison, 1954, p.42), and is absent from Oeno. As a beach-crest scrub it is more common on seaward than on lagoon shores, and is often wind-sheared in consequence; where it does occur on lagoon shores the shrubs are taller and more open with a vertical rather than sloping profile; but unlike Pemphis and Tournefortia, Scaevola rarely becomes a tree. In the northern Cooks, Linton (1933) refers to dominantly lagoon-shore Scaevola at Penrhyn and Manihiki, and low Scaevola occupies lagoon flats at Christmas Island (Jenkin and Foale, 1968).

Inland Scaevola is extensive on several Aitutaki islands, especially Maina and Akitua, where it forms a zone up to 200 m wide between the Suriana scrub and the main woodland area. On Akaiami, Mangere and Angarei it forms a scrub 1-1.5 m tall, with occasional Tournefortia, Pandanus, Guettarda, and Euphorbia chamissonis. Cassytha is locally common, though nowhere reaching the smothering density seen on Scaevola on some Indian Ocean islands (e.g. Assumption: Stoddart et al., 1970, 127). The ground surface is bare with some Fimbristylis. Similar extensive inland scrub is described from Canton (Hatheway, 1955) and Diego Garcia (Stoddart, 1971).

Scaevola under coconuts is less extensively developed on Aitutaki. On Taverua it forms an open scrub up to 1.5 m tall, and similar low open scrub with many other species present has been described from many other Indo-Pacific atolls.

Tournefortia scrub

Tournefortia argentea, though widespread, is a less common component of atoll vegetation than Suriana, Pemphis or Scaevola. It characteristically occurs either as a beach scrub or as an inland scrub-forest. Its Caribbean counterpart, T. gnaphalodes, though smaller, occurs more commonly as a seaward-beach scrub, but never forms trees.

On Aitutaki Tournefortia is not common. It occurs with Scaevola in beach scrub on Mangere and Maina, and probably because of the nature of island topography is more common on channel and lagoon than on seaward shores. In the northern Cooks, on Penrhyn and Manihiki, Tournefortia up to 6 m tall is said to form the main beach scrub (Linton, 1933), and it is characteristic of exposed seaward beaches in the Tokelaus (Parham, 1971) and in the Tuamotus: at Raroia it forms bushes 2-3 m in diameter and height, with a root radius of 40 m (Doty and Morrison, 1953). In the Line Islands, in the absence of Pemphis and Suriana, it is an important beach scrub at Washington, Fanning, Christmas and Palmyra, on lagoon shores as well as seaward shores (Christopherson, 1927; Dawson, 1959).

Inland scrub-forest of Tournefortia is also widespread in

the Pacific, though often now found only as relict patches. It is indeed the main woody vegetation at Pokak, Marshall Islands (Fosberg, 1955), at Gaferut, Caroline Islands (Niering, 1961), at Oeno, Tuamotus (St John and Philipson, 1960) and on Ducie. Groves are also described from Wake, Christmas, Palmyra, Fanning (reaching 12-15 m), Canton and Caroline Atolls. Plants in these groves have well-developed trunks and form gnarled trees rather than shrubs.

Tournefortia seedlings are intolerant of shade, and when mature trees are found under coconut woodland (as on Tekopua), it is presumed that they pre-date the plantation.

Pandanus woodland

At Aitutaki *Pandanus* forms a narrow zone between Coconut-*Guettarda* woodland and low scrub to seaward. On Tavaerua Iti it forms a dense exclusive zone, while on Ee it might more properly be termed a *Pandanus*-*Guettarda* woodland. In pure stands of *Pandanus* the ground is covered with dead leaves and no other plants grow. The more mixed type on Aitutaki is equivalent to Parham's (1971) *Pandanus*-*Guettarda* facies in the Tokelaus, though in the latter many other species (*Cordia*, *Hernandia*, *Morinda*) are also present.

Pisonia woodland (Plate 33)

Relatively small stands of *Pisonia grandis* are found on some Aitutaki motus, the largest covering 10 ha on Tekopua and 4.6 ha on Tapuaeta. On Tekopua the trees are 20 m tall and 3-4 m apart; other tree species, including *Cocos*, *Guettarda*, *Pandanus* and *Morinda* are also present. On Tapuaeta the woodland is more open, with *Hernandia* and *Hibiscus* as well as *Cocos*, *Guettarda* and *Morinda*. There is little undergrowth beneath the *Pisonia* woodland. *Pisonia* is also found, in a mixed *Pisonia*-*Hernandia* woodland, on Papau, and, as scattered trees only, on the Ootu peninsula.

It is possible that *Pisonia* woodland was more extensive before the spread of coconut woodland at Aitutaki. Certainly the trees do not compare in dimensions with those reported from the northern Cooks: Linton (1933) describes trees 23 m tall and 1 m in diameter at Penrhyn and Manihiki. *Pisonia* is the sole tree forming woodland on Vostok (Clapp and Sibley, 1971b), and it forms "magnificent stands" at Palmyra (Dawson, 1959, 14) and on atolls westward through the Marshall Islands and in the Indian Ocean. Agassiz reports *Pisonia* forests from many islands which now have mainly coconut plantations.

Hernandia woodland

Hernandia sonora is a component of woodland on some of the Aitutaki motus, especially those such as Tapuaeta and Papau with stands of *Pisonia*. It may formerly have been more extensive. Aitutaki is close to the eastern limits of the range of

this pantropical species. It is absent from the Tuamotus (though recorded from Mopelia and Tetiaroa in the Societies) and from Palmyra and Christmas Islands in the Line Islands, but is widespread in the Marshalls and other Micronesian and Melanesian areas, where it often forms very large trees.

Guettarda woodland

With Pandanus, Guettarda frequently forms a transitional zone between seaward scrub and coconut woodland on Aitutaki motus. The trees are up to 7 m tall (exceptionally reaching 10 m on Akaiami) and are located on the fringe of the higher leeward sand area rather than on the low sand and gravel sheets of the seaward sides of the islands. Doty (1954, p.28) has suggested that Guettarda is an indicator of the outer edge of the freshwater lens on islands, and also that since it is tolerant of shade it is widely distributed over the surface of islands beneath coconut woodland.

By comparison with the Tuamotus, where it forms the main native woodland on Raroia and Rangiroa (Doty and Morrison, 1954; Stoddart and Sachet, 1969), often in association with Tournefortia and Pandanus, Guettarda is weakly represented at Aitutaki. At Penrhyn and Manihiki in the northern Cooks there are trees of Guettarda 10 m tall; this is the maximum height of trees on Aitutaki (Linton, 1933). The species is absent from the Line Islands, and an introduction at Palmyra proved unsuccessful (Christophersen, 1927; Dawson, 1959).

Although Guettarda is widespread on the Aitutaki motus it is completely absent from the main volcanic island, with the exception of the Ootu Peninsula, which itself is simply a large motu attached to the main island: the first trees of Guettarda found are those at the northern end of the peninsula, with the transition from volcanic to calcareous soils. Guettarda is present on the two southern volcanic islets of Rapota and Moturakau, but on areas of calcareous sand rather than on volcanic substrates.

Casuarina woodland

Groves of Casuarina equisetifolia, presumably introduced, are found on leeward sandy areas of some motus, notably Ee and Angarei. The stands are not large and there is a ground vegetation of Scaevola taccada and Euphorbia chamissonis. Casuarina is also locally common on the main volcanic island.

Calophyllum woodland

Calophyllum inophyllum is absent from the motus and is found only on the volcanic islets of Moturakau and Rapota. On Moturakau it forms a dense canopy, with Hibiscus, Guettarda, Morinda and Leucaena; on Rapota it is associated with Pandanus. Its absence from the motus is surprising. Linton (1933) records

trees 15 m tall on Manihiki in the northern Cooks but stated that it had been destroyed by man at Penrhyn. In the Tokelaus also it may have been removed by man, primarily for firewood. There are scattered trees on most of the Tuamotu atolls, but the Cook Islands are near the eastern limit of its range and it may have been introduced there. Nowhere on Aitutaki does it form the massive trees overhanging lagoon shores, characteristic of many west Pacific and central Indian Ocean atolls (e.g. Kapingamarangi, Diego Garcia).

Coconut woodland (Plate 31)

Coconut woodland is the dominant woodland vegetation on the motus and has been so for at least a century (Gill, 1876, 1885). Only on Akaiami, where cultivation experiments are in progress (Thomson, 1968), are regular plantations maintained; elsewhere the woodland varies from a relatively clear woodland with little undergrowth, as on parts of Tekopua, to a mixed woodland of crowded coconut palms of different ages intermixed with broadleaf trees. Most of the mature coconuts are 8-10 m tall, though some are higher; the common broadleaf trees include Guettarda (to 10 m), Morinda (to 6 m), Pandanus (to 7 m) Leucaena, Pipturus argenteus, and occasionally Tournefortia and tall Hernandia. There is usually a shrub layer of Timonius polygama (1-2 m), Scaevola (1 m), Corchorus torresianus, Euphorbia chamissonis, and, rather rarely, tall Tacca leontopetaloides. The ground layer is highly variable, with Opomoea, Tournefortia, Boerhavia, Portulaca, grasses, sedges, and ferns; the latter are mainly Polypodium scolopendria. Asplenium nidus, common in the wetter atolls of the Line and Marshall Islands and characteristic of dense woodland in the Tokelaus (Dawson, 1959; Parham, 1971), is absent, as is Psilotum nudum. Perhaps the most striking characteristic of the Aitutaki coconut woodland is the restricted composition of the weedy ground layer: few of the many weeds of the main volcanic island are present on the motus, even though some, such as Stachytarpheta, are elsewhere abundant on such islands even where there is no local reservoir such as the main Aitutaki island provides; while others, such as Cenchrus, are found only on one or two motus near landing stages and have failed to spread and establish themselves.

Cladium marsh

There is one area of Cladium jamaicense marsh on Akitua, forming a dense stand up to 2.5 m tall. This species was not collected on other motus, where there are no similar habitats. It surrounds inland marshes at Avatoru and Tereiao, Rangiroa Atoll, in the Tuamotus (Stoddart and Sachet, 1969, pp.28-29, pl. 13), and may be relatively common in the region. It is common on Tetiaroa in what appear to be ancient abandoned taro marshes.

Pioneer beach communities (Plate 26)

Because of the geomorphology of the motus, pioneer beach communities of herbs, vines and grasses are largely limited to lagoon shores and especially to sandspits on the lagoon sides of islands adjacent to channels. The outpost species are mainly *Vigna marina*, *Triumfetta procumbens* and *Ipomoea*, with *Fimbristylis* and *Heliotropium anomalum*. As on other atolls these scattered outpost species can be followed inland through a regular zonation to coconut woodland: on Aitutaki the zonation includes scrub species such as *Euphorbia chamissonis*, *Timonius polygama*, juvenile *Scaevola*, *Tournefortia*, *Suriana* and *Pemphis*, and woodland species such as *Guettarda*, *Pandanus* and coconuts. The succession is well seen on the spit at the south end of Tekopua, and on leeward beaches of Ee, Mangere, Papau, Tavaerua and Tavaerua Iti. In many lagoon and channel areas, however, the beaches are narrow and cliffed, and the outpost species are absent. These herbaceous pioneer communities on sandy substrates are of very small extent by comparison with the pioneer scrub species, *Pemphis* and *Suriana*, on the seaward conglomerate platforms and gravel sheets of the motus.

ABSENT VEGETATION TYPES

By comparison with other Pacific atolls described in recent years, the Aitutaki motus lack a number of well-marked vegetation units. These fall into two categories: anthropogenic types common elsewhere but absent from the motus because cultivation is concentrated on the main volcanic island, and types absent for biogeographical reasons because of the remote location of the Cook Islands in the central Pacific.

Absent anthropogenic vegetation types

Breadfruit (*Artocarpus altilis*) groves are completely absent from the motus, though individual trees are common on the main island. On wetter atolls such as Kapingamarangi and Arno the groves reach heights of 20-30 m (Niering, 1956; Hatheway, 1953). Fosberg (1949) has suggested that the location of breadfruit is controlled by groundwater salinity; islands such as Akaiami and Tekopua on Aitutaki would certainly be large enough for this tree to be grown.

Pits for the cultivation of root crops such as *Cyrtosperma chamissonis*, *Colocasia esculenta* and *Xanthosoma sagittifolia* are prominent and in some cases extensive features of atoll islands in the western Pacific, forming the puraka pits of Kapingamarangi, the babai pits of Onotoa, and the yaraj pits of Arno (Niering, 1956; Moul, 1957; Hatheway, 1953). These pits are found on the main island of Aitutaki but on none of the motus. That they would have been dug on the motus had it not been for the existence of alternative food sources is indicated by their presence on Pukapuka and Palmerston Atolls in the northern Cooks (Wood and Hay, 1970, p.65).

Other absent vegetation types

The absence of mangroves and of sea-grasses in the Cooks has already been noted. This is perhaps the most obvious cause of contrast with the reefs and islands of Tonga and islands to the west and of similarity with the Tuamotus and islands to the east. The place of the former is taken on mainland shores of Aitutaki, and on the protected shores of Ngatangiia Harbour on Rarotonga, by dense thickets of Hibiscus tiliaceus, and elsewhere by a continuous saturated sward of Paspalum and other grasses.

The absence of Calophyllum and Barringtonia woodland from the motus has also been noted. Calophyllum is present on reef islands elsewhere in the Cooks, and Barringtonia is common on Aitutaki itself. If either ever existed on the motus they may have been cut for firewood; but the existence of Calophyllum woodland on the southern volcanic islets suggests that this is not the true explanation and that the species was never important on the motus.

Cordia subcordata woodland is also absent from the motus, though the species is found on Akitua. It is common in the Tokelaus, forms the main native woodland on Canton and Caroline Atolls (Hatheway, 1953, 3; Clapp and Sibley, 1971b), but is "almost rare" at Raroia in the Tuamotus (Doty, 1954, p.26). Yet in the northern Cooks, at Penrhyn and Manihiki, it is reported to form trees 15-25 m tall and up to 0.6 m in diameter (Linton, 1933).

Certain fleshy herbaceous vegetation types are also absent. Portulaca is curiously rare and nowhere on the motus forms a vegetation unit, though at Canton (a much drier atoll), for example, it forms the most extensive vegetation (Hatheway, 1954, p.6). Sesuvium portulacastrum is unrecorded from Aitutaki, though present on the reef islands of Rarotonga; Wilder (1931) however noted it as rare at the latter island. At Christmas Island and in the Phoenix Islands Sesuvium mats are extensive (Jenkin and Foale, 1968). The species is absent from the Tokelaus and the Marshalls, but present in Phoenix, Wake, and Hawaii, and its distribution might merit further study. Other herbaceous vegetation units unrepresented or weakly represented on the Aitutaki motus include grasses such as Lepturus and Sporobolus (which also is absent from the Marshall Islands); and the Ipomoea-Wedelia-Stachytarpheta type often widespread under coconuts. For further details of these types, see the accounts by Fosberg (1953, 1974).

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Table 11. Size of Pacific atoll floras

Group	Atoll	Number of species (number of indigenous species in brackets)		Source
Marshalls	Ailuk	56	(26)	Fosberg 1955
	Arno	125	(40)	Hatheway 1953
	Bikini	41		Taylor 1950
	Eniwetok	100	(33)	St John 1960
	Jaluit	288	(60)	Fosberg and Sachet 1962
	Jemo	34	(17)	Fosberg 1955
	Kwajalein	89	(25)	Fosberg 1955, 1959
	Lae	61	(35)	Fosberg 1955, 1959
	Likiep	91	(31)	Fosberg 1955, 1959
	Pokak	9		Fosberg 1955
	Rongelap	42		Taylor 1950, Fosberg 1959
	Taka	23	(18)	Fosberg 1955
	Ujae	61	(32)	Fosberg 1955, 1959
	Ujelang	50	(29)	Fosberg 1955, 1959
	Utirik	55	(26)	Fosberg 1955, 1959
	Wotho	40	(28)	Fosberg 1955, 1959
Solomons	Ontong Java	150	(58)	Bayliss-Smith 1973
Carolines	Ant	58		Glassman 1953
	Kapingamarangi	99	(43)	Niering 1962
	Namonuito	94		Stone 1959
	Pingelap	78		St John 1948
	Puluwat	42		Niering 1961
Gilberts	Onotoa	60	(50)	Moul 1957
	Tabiteuea	45		Luomala 1953

Table 11 continued

Group	Atoll	Number of species (number of indigenous species in brackets)		Source
	Tarawa	109	(28)	Catala 1957
Ellice	Funafuti	55		Maiden 1904
Tokelaus	Fakaofo	40		Parham 1971
	Nukunono	55	(35)	Parham 1971
Phoenix	Canton	164	(14)	Degener and Gillaspy 1955
Line	Christmas	41		Chock and Hamilton 1962
	Palmyra	64		Dawson 1959
Cooks	Aitutaki (motus)	45		This paper
	Manihiki	22		Cranwell 1933
	Rarotonga (motus)	41		Stoddart and Fosberg 1972
Societies	Mopelia	78		Sachet in litt.
Tuamotus	Oeno	17	(14)	St John and Philipson 1960
	Mururoa	26		Chevalier et al. 1968
	Rangiroa	121	(39)	Stoddart and Sachet 1969
	Raroia	135	(54)	Doty 1954
Hawaii	Kure	42	(23)	Lamoureux 1961, Clay 1961
	Laysan	38	(27)	Lamoureux 1963, Tsuda 1965
Others	Rose	4		Sachet 1954
	Caroline	35		Clapp and Sibley 1971a
	Flint	36	(13)	St John and Fosberg 1937
	Vostok	2		Clapp and Sibley 1971b
	Clipperton	31	(14)	Sachet 1962
	Wake	94	(20)	Fosberg 1959b, Fosberg and Sachet 1969

Table 12. Numbers of species of vascular plants on Aitutaki and Rarotonga islands

Island	Area ha	Tree species	Shrub species	Herb species	Total number of species
AITUTAKI					
Ootu	ca 175	8	12	22	42
Akitua	14.9	8	9	12	29
Angarei	13.1	6	8	6	20
Ee	29.2	7	7	7	21
Mangere	8.5	5	6	8	19
Papau	5.3	8	7	10	25
Tavaerua Iti	4.1	5	7	10	22
Tavaerua	12.5	4	6	8	18
Akaiami	41.9	5	9	8	22
Muritapua	4.0	3	5	8	16
Tekopua	71.3	7	10	9	26
Tapuaeta	6.0	7	8	6	21
Sand cay	1.0	1	3	1	5
Motukitiu	11.5	5	8	10	23
Moturakau	3.9	7	3	6	16
Rapota	-	11	3	6	20
Maina	17.0	4	5	10	19
RAROTONGA					
Motutapu	11.0	7	3	14	24
Oneroa	10.6	8	6	6	20
Koromiri	3.0	6	3	8	17

Table 13. Distribution of tree species on Aitutaki motus

	Tapueta cay	Muritapua	Tavaerua Iti	Papau	Tapuaeta	Mangere	Motukitiu	Tavaerua	Angarei	Akitua	Maina	Ee	Akaiami	Tekopua	Ootu	Moturakau	Rapota	Total
Cocos nucifera	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	17
Guettarda speciosa		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	16
Pandanus tectorius		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	16
Morinda citrifolia				x	x		x	x	x	x			x	x	x	x	x	11
Casuarina equisetifolia			x	x		x			x	x		x		x	x		x	9
Hibiscus tiliaceus			x		x						x	x	x		x	x	x	8
Hernandia sonora				x	x		x		x					x			x	6
Leucaena insularum				x		x				x		x			x	x		6
Pisonia grandis				x	x							x		x	x			5
Calophyllum inophyllum																x	x	2
Carica papaya										x								1
Cordia subcordata										x								1
Erythrina variegata																	x	1
Mangifera indica																	x	1
Thespesia populnea																	x	1
Total	1	3	5	8	7	5	5	4	6	8	4	7	5	7	8	7	11	

Table 14. Distribution of shrub species on Aitutaki motus

	Tapuaeta cay	Muritapua	Tavaerua Iti	Papau	Tapuaeta	Mangere	Motukitiu	Taverua	Angarei	Akitua	Maina	Ee	Akaiami	Tekopua	Ootu	Moturakau	Rapota	Total
Scaevola taccada	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	17
Pemphis acidula		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	15
Suriana maritima	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			15
Tournefortia argentea	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	16
Euphorbia chamissonis		x	x	x	x	x	x	x	x	x	x	x	x	x	x			14
Timonius polygama			x	x		x		x	x	x		x	x	x	x			10
Sophora tomentosa				x	x					x		x	x	x	x	x		8
Colubrina asiatica					x		x		x		x		x	x	x			7
Capparis cordifolia							x						x	x	x			4
Pipturus argenteus			x		x		x							x				4
Corchorus torresianus									x	x					x			3
Sida rhombifolia										x								1
Solanum nigrum															x			1
Crotalaria pallida															x			1
Total	3	5	7	7	8	6	8	6	8	9	5	7	9	10	12	3	3	

Table 15. Distribution of herb species on Aitutaki motus

	Tapuaeta cay	Muritapua	Taverua Iti	Papau	Tapuaeta	Mangere	Motukitiu	Tavaerua	Angarei	Akitua	Maina	Ee	Akaiami	Tekopua	Ootu	Moturakau	Rapota	Total
Stenotaphrum micranthum		x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	15
Fimbristylis cymosa		x	x	x	x	x	x	x	x	x	x	x	x	x	x			14
Heliotropium anomalum	x	x	x	x		x	x	x	x		x	x	x	x	x			13
Polypodium scolopendria		x	x	x	x	x	x	x		x	x	x		x		x	x	13
Triumfetta procumbens		x	x	x	x	x	x	x	x	x	x	x			x			12
Cassytha filiformis		x		x			x	x	x	x	x	x	x	x	x			11
Vigna marina			x			x	x	x	x			x	x	x	x	x	x	11
Tacca leontopetaloides		x	x	x	x	x		x			x		x	x			x	10
Ipomoea pes-caprae				x		x				x					x	x	x	6
Ipomoea macrantha		x	x				x			x	x				x			6
Lepidium bidentatum				x							x		x	x				4
Portulaca oleracea				x	x						x				x			4
Cenchrus echinatus										x				x	x			3
Abrus precatorius																x	x	2
Boerhavia tetrandra			x				x											2
Bidens pilosa										x					x			2
Emilia sonchifolia										x					x			2
Digitaria ciliaris			x												x			2

Table 15 continued

	Tapuaeta cay	Muritapua	Taverua Iti	Papau	Tapuaeta	Mangere	Motukitiu	Tavaerua	Angarei	Akitua	Maina	Ee	Akaiami	Tekopua	Ootu	Moturakau	Rapota	Total
Achyranthes velutina							x											1
Boerhavia repens										x								1
Cladium jamaicense										x								1
Sporobolus												x						1
Vernonia cinerea																x		1
Unident. grass													x					1
Total	1	8	10	10	6	8	10	8	6	12	10	7	8	9	22*	6	6	

* includes 10 additional species not listed here

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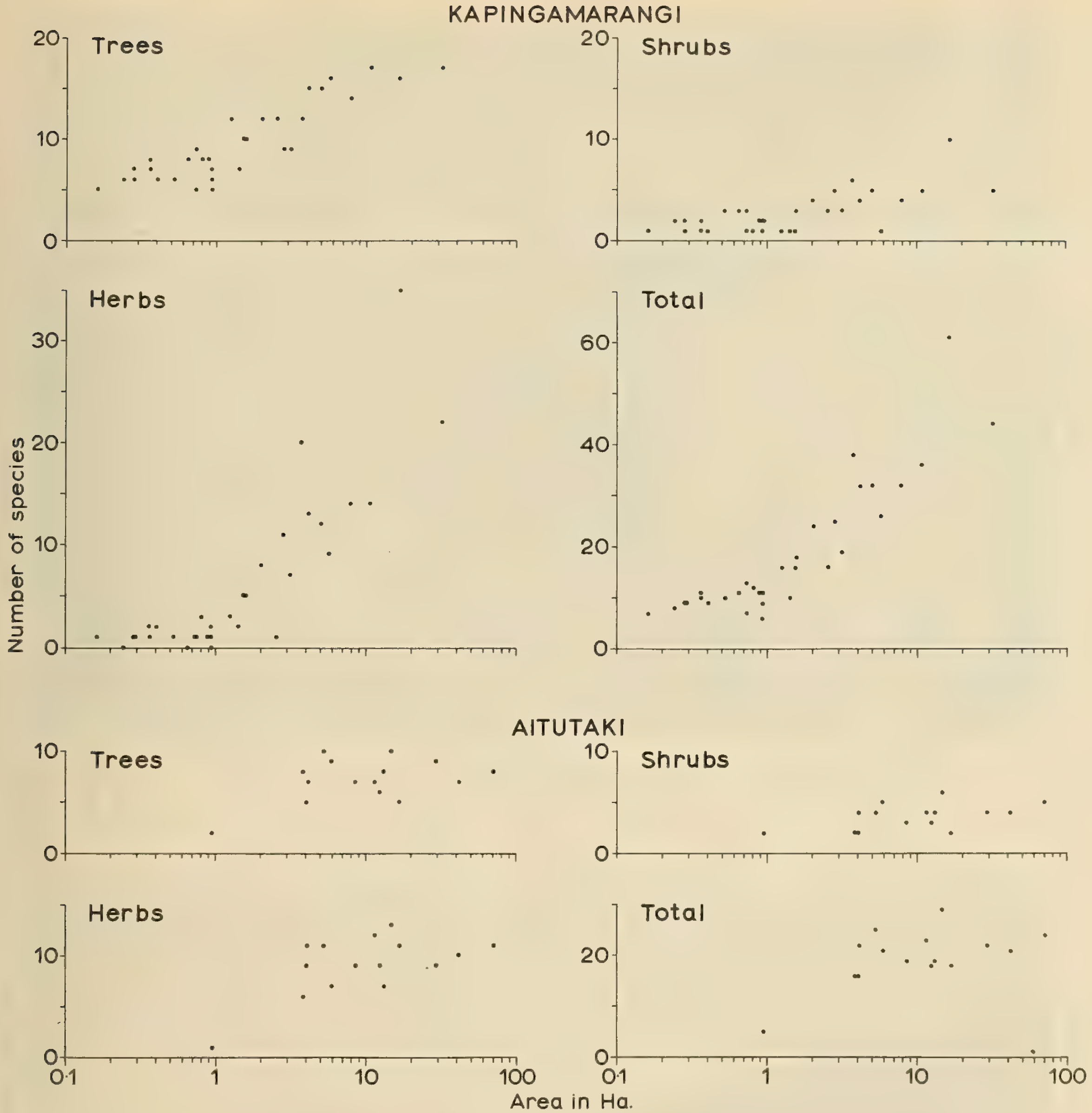

Figure 33. Numbers of species and island area for trees, shrubs and herbs at Kapingamarangi and Aitutaki

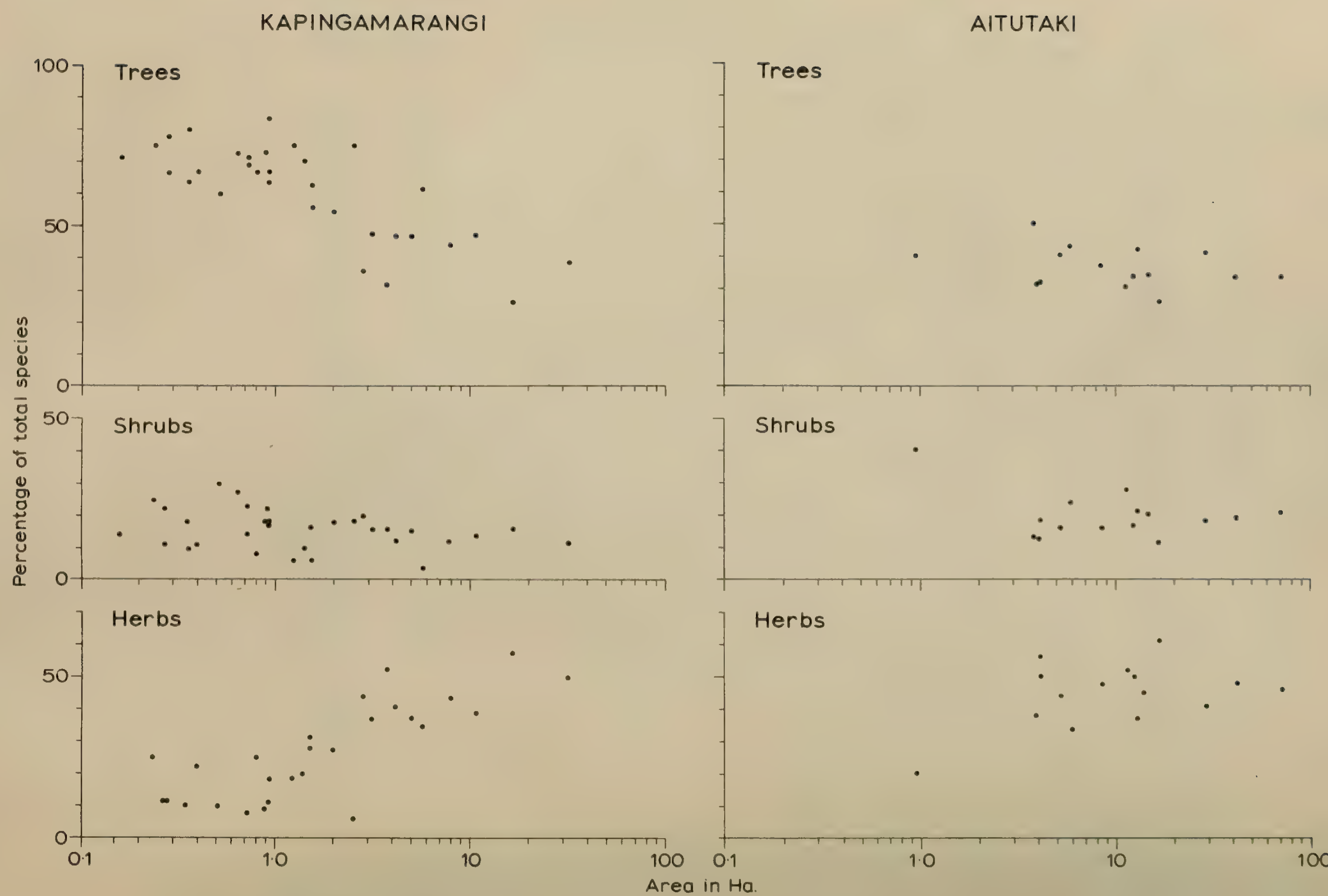

Figure 34. Numbers of species of trees, shrubs and herbs as percentages of total flora at Kapingamarangi and Aitutaki

26 Pioneer <u>Heliotropium</u> at Motukitiu

27 <u>Scaevola</u> scrub, north end of Akaiami

28 Pemphis scrub and leeward woodland at Ee

29 Pemphis scrub and leeward woodland at Muritapua

30 Mixed woodland at the south end of Tekopua

31 Coconut woodland on Motukitiu

32 Tacca on Akaiami in coconut woodland

33 Pisonia woodland on Tapueta

7. MAINLAND VEGETATION OF AITUTAKI

D.R. Stoddart

Though only incidental observations were made on the main island of Aitutaki, few observations on its vegetation have appeared in the literature since Bligh's notes in 1789, and this chapter therefore places on record notes on the vegetation types and their distribution, with emphasis on coastal areas. The greater part of Aitutaki is actively managed by man, and no areas escape human interference: the vegetation units described, therefore, are largely human artefacts, just as many of their component species have been introduced by man, either in pre-contact or more recent times.

The vegetation can conveniently be considered in categories defined by topography: (a) the coastal flat and beaches; (b) the slopes to higher ground, which in places reach the coast to form promontories or cliffs; (c) inland plateaux and rolling ground, largely cultivated and occupied by villages; and (d) hills, steep slopes and crags. Most information is available for the first of these categories, though collections and observations were made in all of them (Figure 35). Comparable types have been described from the lowlands of Rarotonga by Cheeseman (1903), Wilder (1931), and Philipson (1971).

COASTAL FLAT AND BEACHES

The coastal flat is discontinuously developed, being most extensive southwards from Nikaupara on the seaward coast and northwards from Vaipeka to Te O on the lagoon coast. Elsewhere it may be absent and basalt slopes reach directly to the sea. The coastal flat is an aggradation terrace of calcareous and volcanic sands, but even where the sands are dark coloured the calcium carbonate content is likely to be high.

Northwest coast

At Marutea the beach is exceptionally wide, reaching 50 m, with a zone of pioneer species (*Triumfetta procumbens*, *Heliotropium anomalum*, juvenile *Casuarina*) up to 35 m wide. The coastal flat is covered with an open woodland of *Guettarda* (9 m tall), *Cocos*, *Hibiscus*, trees of *Tournefortia*, and *Pandanus*, in a scrub of *Scaevola taccada* 1-1.5 m tall, with some *Suriana* and *Sophora*, and a ground cover of *Triumfetta*, *Heliotropium*, *Ipomoea macrantha*, and grasses (*Sporobolus africanus*, *Panicum reptans*). This sector may be regarded as the northern end of the Ootu peninsula, in effect a tied motu, rather than part of the mainland proper.

The coastal flat narrows southwards and the ground rises

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steeply from the sea to the crags of Maungapu Hill. At Vaiuoe there is a narrow beach, with a beach-crest zone of Paspalum 10 m wide, backed by a mixed woodland of coconut and Casuarina with Hernandia and Hibiscus. Other outpost species of scattered distribution along this sector include Triumfetta, and juvenile Scaevola, Sophora, Hibiscus and Casuarina. Vigna marina extends back into the woodland. The flat widens south of Perekiatu, but consists of low-lying volcanics as well as aggradation deposits; and it is continuously occupied by settlements from Perekiatu to Nikaupara.

Southwest coast

The coastal flat in this sector extends in shallow embayments between low rocky points or promontories; small streams flow out into the bays. Between Rapae and Rangiteia the coastal flat is 50-100 m wide and covered with coconut woodland with Hibiscus and Hernandia. Beginning here and becoming more continuous further south is a coastal fringe of Casuarina with some Hibiscus and Calophyllum and occasional Pandanus. The beach outpost vegetation consists of grasses and seedlings of Suriana and Sophora.

Between Rangiteia and Pata the flat is 90-100 m wide. It is again covered with coconut and Hibiscus woodland reaching about 15 m, with several other trees, including Hernandia (to 20 m), Leucaena, Pandanus and Morinda citrifolia (6-8 m), with, rarely, Inocarpus fagifera. The ground cover consists of Fimbristylis cymosa, Cyperus, Hippobroma, Stachytarpheta, Mimosa pudica, and Sida rhombifolia. Groves of Pandanus and Casuarina have little ground vegetation; near streams Pandanus grows luxuriantly with Cyperus alternifolius 1.5 m tall beneath. The beaches are narrow at the promontories (3 m wide) and wider (to 10 m) in the bays. The main beach vegetation is a meadow of Paspalum with Fimbristylis.

Southwards to Aretere the flat reaches a width of 120 m. There is a coastal fringe of Casuarina, then a zone 30-50 m wide of coconut-Hibiscus woodland with low Casuarina; and finally a zone of massive Barringtonia and Hernandia with ferns beneath. Pandanus and Inocarpus are also present. Ground cover in the coconut woodland consists of grasses, Vigna marina, Hippobroma, and seedlings of Sophora. The grasses include Cenchrus echinatus. There is no beach in this sector: the edge of the coastal flat is cliffed and eroding, and Casuarina roots are exposed on the shore.

At Tekoutu Point there is a thicket of Hibiscus, passing back into a mixed woodland of Cocos, Hernandia and Hibiscus. The ground cover consists of Cenchrus, Vigna, Triumfetta and ferns; other trees present are Guettarda, Casuarina and Pandanus; and there are tall shrubs on the coast of Sophora, some 6 m tall. South of the point the erosion is replaced by aggradation. There is a wide lobe of recent sand, with pioneer

Ipomoea pes-caprae and Fimbristylis; grasses; a shrub zone of Scaevola and Sophora 1.5 m tall, with juvenile Casuarina; and on the coastal flat a mixed woodland of Cocos, Hibiscus, Leucaena, Casuarina, Pandanus and Guettarda.

Southeast coast

Approximately from Tekoutu to Teaitu the coastal flat has very similar characteristics: it is narrow, has a well-developed Casuarina fringe, and is covered with coconut woodland passing back into a broadleaf woodland. Immediately east of the point the flat is narrow and cliffed. The Casuarina fringe is 20 m wide, with occasional coastal Pandanus. Big trees of Hernandia reach the sea at one point, with spreading low branches. The coconut woodland contains occasional trees of Hernandia, Calophyllum and Leucaena. Sophora is the only shrub. The ground surface under the coconut woodland is mainly bare, with scattered Hippobroma, Triumfetta, Vernonia cinerea and Vigna marina. Ferns and Psilotum grow on coconut boles. Inland the coconut woodland is replaced by a Hibiscus woodland with Morinda and Pandanus.

At Vaiotango the coconut-Hibiscus-Guettarda woodland is about 100 m wide. Tall Scaevola (5 m) and Sophora grow near the shore, with Ipomoea indica, Hippobroma, Vigna and Triumfetta beneath the woodland. There are scattered tall trees of Calophyllum. Hibiscus and Pandanus are less important here than further south. Inland the woodland is replaced by Barringtonia and Guettarda, or Casuarina. At Vaiokora the Casuarina coastal fringe is re-established, and is here 20 m wide. The coconut woodland contains Calophyllum, Hibiscus, Leucaena, Morinda and Pandanus, with Scaevola, Sophora and Hippobroma. At Teruarei the Casuarina fringe is interrupted in places by Hernandia and some Pandanus. The coconut woodland is 70-85 m wide, with massive Hernandia and Calophyllum and much Morinda. The ground cover is again sparse, and is dominated by Hippobroma and Thelypteris forsteri. At Teaitu the Casuarina fringe is more continuous, with occasional trees of Hernandia, Guettarda and Barringtonia. Occasional Calophyllum and Barringtonia are found in the woodland of Cocos, Pandanus and Hernandia, with shrubs of Sophora and Scaevola and Hippobroma on the ground. These brief notes indicate the essential uniformity of vegetation in this sector.

Towards the Tautu jetty the coast erosion becomes less marked and the coastal flat widens to 100 m. The Casuarina fringe gives way to Hibiscus thicket and grass turf, with Hernandia and Pandanus on the flat. Pemphis, uncommon on most of the mainland coast, grows along the whole length of the old jetty.

East coast

North of the Tautu jetty the coastal flat is interrupted

by a cliffy sector where volcanic rocks reach the coast, but it is resumed north of Vaipae. At Vaipae itself the flat is narrow but the coast is fringed by a very distinctive band, 10-15 m wide, of a wet Paspalum marsh with Echinochloa colonum and Cyperus cyperoides (Plate 36). Immediately inland of this is a thicket of Hibiscus and Pandanus, with ferns, intersected by almost tunnel-like paths leading to the village.

At Vaipeka the coastal flat has widened to 200-270 m (Plate 37). The Paspalum fringe is continuous at the seaward margin, and the flat itself is much lower than on the west side of the island. Shrubs of Pemphis and Hibiscus occur intermittently along the shore. The coconut woodland on the outer part of the flat is 40-50 m wide. There are trees of Hernandia and Hibiscus and occasional Morinda, with sedges beneath. It is more apparently a managed coconut plantation than that around the south coast. Moving north the flat widens to 300 m, and the coconut woodland to 60-70 m. Other trees noted include Casuarina, Pandanus, Morinda and occasional Calophyllum. At the northern end of the main island, at Te O, however, the flat narrows to 10-15 m and is then replaced by a low beach ridge separating the lagoon proper from the barachois (Plates 38 and 39). Pemphis covered with Cassytha and largely dead Hibiscus occur on the ridge. The barachois itself is unvegetated, except for scattered islands covered with a scrub of Pemphis 2 and in places 3 m tall. Juvenile Casuarina, Cyperus and Fimbristylis were also seen on these islands. Pemphis scrub extends round the margins of the barachois and is continuous with that along the lagoon shore of the Ootu peninsula.

SLOPES TO HIGHER GROUND

The inner edge of the coastal flat is uniformly marked by a transition from coconut or broadleaf woodland to dense Hibiscus tiliaceus thicket. In the northwest this is narrow, because of the steepness of the ground. In the southwest, at Pata and Aretere the Hibiscus is less dense, with Morinda, Leucaena and Calophyllum: there is frequently a wet taro patch on the inner coastal flat at the junction with higher ground. A similar pattern extends round the south coast, with Hibiscus, Morinda and Pandanus thicket often separated from the flat by taro patches. On the lagoon coast at Vaipae the thicket is particularly dense, reaches a height of 8-9 m, and is composed of little but Hibiscus: this continues north to Te O.

In places the volcanic slopes reach the sea. On the west coast the largest such case is at Perekeiatu (Black Rocks). The margins of this spur support a woodland of Hernandia, Hibiscus and Casuarina, with some Pandanus. Small Scaevola bushes and Vigna marina form the beach vegetation. On the spur itself tall Calophyllum woodland reaches the sea. The vegetation is very similar to that of Moturakau and Rapota previously described.

Between Arutanga and Rapae volcanic rocks again reach the shore, and the coastal flat is narrow or non-existant. The slopes are covered with a thicket of Hibiscus 6-10 m tall, with a woodland of coconut, breadfruit and kapok behind. There is a narrow zone of Paspalum meadow along the foot of the Hibiscus zone. Ipomoea littoralis was collected beneath the Hibiscus. Low basalt points outcrop to the south, for example at Pata, but these are mainly inconspicuous. At Aretere, however, the point consists of basalt boulders 0.5 m in diameter. Dense Hibiscus thicket reaches the sea.

On the lagoon shore, north of Tautu jetty, the coastal flat narrows and disappears, and is replaced by a cliff up to 8 m high, with an intermittent sloping platform beneath up to 20 m wide, all cut in weathered red clays. Hibiscus and Calophyllum grow on the flat with massive Barringtonia, Calophyllum and Pandanus on the cliff and slopes above.

INLAND PLATEAUS

Most of the inland part of the main island consists of rolling ground 15-50 m above the sea. It is extensively cultivated and settled, and is either occupied by plantations of banana, citrus, and coconuts; groves of mango, breadfruit, Inocarpus, Eugenia jambos, and Carica; or secondary vegetation. Large areas are covered by Ocimum suave, and by a low scrub of Sida rhombifolia. Larger trees include old gnarled Hibiscus at Arutanga, tall Ceiba pentandra, and Hernandia up to 50 m high (most are 15-20 m). Calophyllum reaches 20 m, scattered massive Barringtonia 10-15 m, and at Vaipae there is a huge ancient banyan. There are dense local groves of Pandanus varieties (Plate 35) and Cordyline. All form a patchwork mosaic with cultivated useful and decorative plants. Useful trees include Aleurites moluccana, Persea americana, and Terminalia catappa, besides those already mentioned. The very wide variety of decorative trees includes Acacia farnesiana, Adenanthera pavonina, Araucaria heterophylla, Barringtonia asiatica, Bauhinia monandra, Caesalpinia pulcherrima, Delonix regia, Erythrina variegata, Plumeria, Poinsettia, Spathodea campanulata, and doubtless many others. Decorative shrubs, by no means confined to the villages proper, include Acalypha godseffiana, Acalypha wilkesiana, Bougainvillea, Clerodendrum speciosissimum, Crotalaria pallida, Hibiscus hybrids, Ocimum suave, Nerium indicum, Tabernaemontana divaricata, and again many others.

The greatest diversity, however, is in the introduced decorative and weedy herbaceous flora in this inland zone. Fosberg's list in this Bulletin includes over a dozen species in each category. Many food plants are also introduced; some are included in Fosberg's list; others are listed by Johnston (1967).

HILLS AND CRAGS

The main vegetation on the slopes of Maungapu Hill, the highest point on the island, consists of a grass, Sorghum bicolor, growing to 2 m, and a shrub reaching the same height, Crotalaria pallida (Plate 34). Other shrubs include Triumfetta rhomboidea and Sida rhombifolia. Coconuts rise to immediately below the summit. Before 1942, when they were cleared by troops building military installations, it is said they extended over the summit itself at 119 m. Weedy species now extend over the whole hill and no trace of native vegetation remains. These weeds include Mimosa pudica, which is very common, Vernonia cinerea, Sporobolus africanus, Dactyloctenium aegyptium, Passiflora rubra, Emilia sonchifolia, Euphorbia hirta, and Stachytarpheta urticifolia. It is clear that no areas of indigenous vegetation comparable to those of higher islands like Rarotonga survive on Aitutaki. Bligh's reference to "lawns" on the hills in the eighteenth century suggests that the process of transformation of the vegetation is an old one.

DISCUSSION

A few points of interest may be noted, particularly in contrasting the main island vegetation with that of the motus. Two tree species from the motus are absent from the main island (Pisonia grandis, Cordia subcordata), and one of the most common is restricted and relatively rare (Guettarda speciosa). Similarly the most common shrubs of the motus are absent from the main island. These include Corchorus torresianus, Timonius polygama and Euphorbia chamissonis. Capparis cordifolia is also absent. Scaevola, Suriana and Pemphis are restricted and uncommon, in sharp contrast to the motus, and only Sophora is more common on the main island than on the motus, of the plants characteristic of the latter. The absence on Aitutaki of Coccoloba uvifera, which is a common introduced tree on the coast of Rarotonga, may be noted. The marked disparity in numbers of weedy species between the mainland and the motus on Aitutaki has already been noted.

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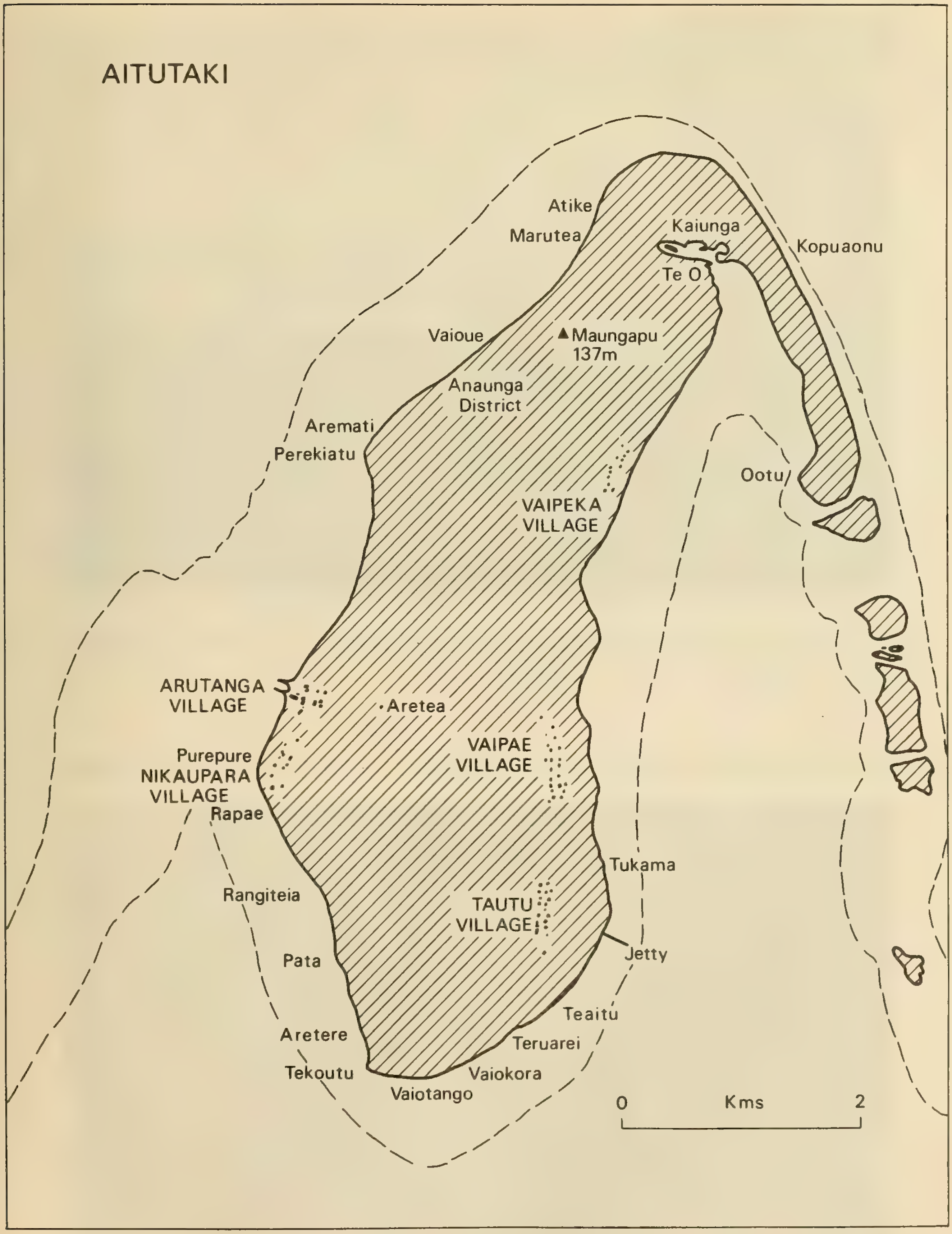

Figure 35. Aitutaki mainland vegetation localities

34 Motus and reef from Maungapu Hill; note the extent of cultivation on the mainland

35 Pandanus grove by the roadside, mainland near Vaioue

36 Paspalum marsh along the lagoon shore of the mainland near Vaipae

37 Sandy lagoon shore of the mainland between Vaipeka and Te O

38 Barachois at Te O

39 Barachois and lagoon beach ridge at Te O

8. SURVEY OF THE MACROFAUNA INHABITING LAGOON DEPOSITS ON AITUTAKI

P.E. Gibbs

INTRODUCTION

Whilst various aspects of the marine faunas of many of the remote islands in the Central Pacific have been investigated, few studies have been directed towards the benthic, soft-bottom communities inhabiting atoll lagoons. In recent years ecological surveys of the lagoon benthos, especially of the molluscs and echinoderms, have been carried out at a number of the Tuamotu atolls, notably Mururoa and Réao (see Chevalier et al, 1968; Renaud-Mornant et al, 1971; Salvat, 1967, 1971, 1972; Salvat and Renaud-Mornant, 1969) and these studies have demonstrated the great variability of the lagoon communities according to the atoll structure and related sedimentological processes. This chapter describes the composition and distribution of the macrofauna within the lagoon on Aitutaki in the southern Cook Islands, a survey of which was carried out in August-September, 1969, as part of the Cook Bicentenary Expedition, organised by the Royal Society of New Zealand.

Descriptions of Aitutaki (latitude 18° 51'45"S, longitude 159° 48'10"W) will be found in Gibbs et al. (1971), Stoddart (this Bulletin) and Summerhayes (1971). Briefly, Aitutaki is an almost-atoll with an area of about 100 km^2, approximately half of which is lagoon (Fig.36). Most of the lagoon is shallow, three quarters of its area being less than 4.5 m deep, and with a maximum depth of only 10.5 m. The tidal range at Aitutaki is small, about 0.5 m at springs.

Investigations were limited to the macrofauna, using this term in the sense of McIntyre (1971) i.e. comprising mainly the infauna of uncompacted sediments retained on a sieve of about 0.5 mm mesh. The positions of the stations sampled in the survey are shown in Fig.36. The littoral fauna was investigated at ten stations, eight around the mainland and two on the eastern reef at Ootu and Tekopua. At these stations the fauna was collected by digging and also sieving samples of sediment through 0.5 mm or 1.0 mm mesh. The bottom fauna of the lagoon was sampled at 20 stations, chiefly located in the eastern half of the lagoon, using a hand-operated naturalist dredge recovering 15-20 l of sediment. The infauna of these samples was separated by sieving through meshes of 0.5, 1.0 or 2.0 mm, the mesh size used depending on the sediment grade.

The lagoon sediments are almost entirely calcareous; even on the shores of the mainland the non-calcareous fraction is small (Stoddart, 1975). Three main deposit zones may be distinguished within the lagoon: (i) the poorly-sorted silty sands forming the extensive intertidal flat and shallow shelf around the mainland (Stations 1-8); (ii) the well-sorted medium to coarse sands, found around the reef islands and on the reef rim (Stations 10, L1-L9); and (iii) the poorly-sorted, fine sands, often with considerable admistures of silt, which cover the lagoon floor (Stations L10-L20).

FAUNA OF THE LITTORAL DEPOSITS

Mainland shore

Along the eastern shore of the mainland the broad sandflat that is exposed at low water springs for a distance of up to 400 m, was chiefly studied at Station 5 but similar observations were made at Stations 4 and 6. A notable feature of this flat is the absence of seagrasses. The number of species found on this flat is relatively low (Table 16) and, for the most part, the fauna is sparse.

The surface-burrowing forms are chiefly gastropods, the commonest of which are *Cerithium variegatum* Quoy and Gaimard, *Pyramidella acus* (Gmelin) and *Rhinoclavis asper* (L.) - the latter being a characteristic lagoon species of Pacific Islands (Morrison, 1954). Less frequent are *Natica gaultieriana* Recluz, *Atys cylindrica* (Helbling) and the bivalve (*Gafrarium pectinatum* (L.). The infauna is dominated by sedentary polychaetes, particularly the chaetopterid species *Mesochaetopterus sagittarius* (Claparède), *Phyllochaetopterus elioti* Crossland, and *Spiochaetopterus costarum* (Claparède), together with fewer individuals of *Phyllochaetopterus brevitentaculata* Hartmann-Schröder, *Glycera lancadivae* Schmarda, *Armandia melanura* Gravier, *Dasybranchus caducus* (Grube) and *Malacoceros indicus* (Fauvel). An errant polychaete, *Marphysa macintoshi* Crossland, and two deep-burrowing bivalves, *Asaphis violascens* (Forskål) and *Quidnipagus palatum* Iredale, mainly occur along the landward edge of the flat where they penetrate cracks in the underlying clay-like rock. Species found under boulders lying on the sand surface include *Siphonosoma cumanense* (Keferstein), *Callianassa* (*Callichirus*) sp. (near *C. placida* de Man), *Alpheus* spp., *Calcinus latens* (Randall), *Clibanarius humilis* (Dana) and *Cypraea moneta* (L.).

Over the outer (lagoonward) half of the flat the burrows of the large mantis shrimp *Lysiosquilla maculata* (Fabricius) are very conspicuous although from the surface indications, few burrows appeared to be occupied, a feature that could not be verified owing to the great depth to which this species burrows. No specimens were captured by the author, the species being identified from a specimen (c.250 mm in length) purchased from

a local fisherman. The deposit-feeder Holothuria atra Jaeger (see Bonham and Held, 1963) is fairly numerous in this area: many of these holothurians were examined for the commensal polynoid Gastrolepidia clavigera Schmarda but none of the latter were discovered despite the fact that this association is to be found on the outer reefs (see Gibbs, 1972). Crabs are frequently encountered ranging over the flat in shallow water; they include Calappa hepatica (L.), Thalamita admete (Herbst), Thalamita crenata (H. Milne Edwards), Metopograpsus thukuhar (Owen) and Percnon planissimum (Herbst), as well as several species of hermits, and probably all of these species are widespread in the lagoon. The largest of the lagoon crabs, Scylla serrata (Forskål), is generally trapped by local fishermen in nets laid in the muddier, northern part of the lagoon; the larger of two purchased specimens measures 20 cm across the carapace.

Along the landward edge of the flat, between the levels of about low water neaps and high water springs, the beach profile is steeper. In this narrow strip the ocypodid crabs Macrophthalmus (Macrophthalmus) convexus Stimpson and Uca tetragonon (Herbst) are common, the former extending from the upper levels of the flat to about mid-tide level and the latter from about mid-tide level up towards high water mark. Both species are found along the length of the eastern shore of the mainland but are commonest in the muddier deposits to the north, particularly in the backwater of Te O (Stations 7 and 8). On the other hand, the ghost crab Ocypode laevis Dana appears to be confined to the more southerly shoreline (e.g. Station 4) where it is found burrowing in moist sand at high water level. The land crab Cardisoma carnifex (Herbst) is found on the mainland but its distribution was not studied.

Along the lagoon shore of the mainland, in a narrow zone about mid-tide level, two spionid polychaetes dominate the infauna: these are Malacoceros indicus and Scolelepis (Scolelepis) squamata saipanensis Hartman, both of which form dense, often mixed, populations. Below this level, in the less silty deposits along the southern shoreline (Stations 2 and 3), the small opheliid Armandia melanura is frequently the only infaunal species but in patches Mesochaetopterus sagittarius occurs, its densely aggregated tubes often forming prominent, raised hummocks.

Special mention should be made of the polychaete Ceratonereis vaipekae Gibbs, a species described from the material of the present survey. This small nereid is very abundant amongst the Uca burrows at Te O (Station 8) and it is also found amongst the roots of shoreline grasses (at Station 6) often with the intertidal oligochaete Pontodrilus matsushimensis Iizuka. It seems likely that C. vaipakae is able to tolerate periods of lowered salinity since in these habitats brackish conditions must occur with surface run-off after heavy rainfall.

Reef shores

The fauna of the lagoon shores of the eastern reef was investigated at two localities, namely at Ootu (Station 9) where the intertidal flat is composed of silty, fine sand, and at the southern end of Tekopua Island where the littoral deposits are medium to coarse sands. The main difference between the fauna at these two localities and that of the mainland shore is the presence of the enteropneust *Ptychodera flava* Eschscholtz, the abundance of which is clearly indicated by the numerous faecal casts on the sand surface. However, apart from this species, the fauna at Ootu is similar to that found on the flat of the mainland, with the three chaetopterids *M. sagittarius* *P. elioti* and *S. costarum* being the dominant elements of the infauna, except that here the surface burrowing gastropods are remarkably scarce, only one specimen of *Pyramidella acus* being found.

At Tekopua (Station 10) the infauna is again dominated by chaetopterids but the species are different, namely *Phyllochaetopterus verrilli* Treadwell and *P. brevitentaculata*. Apart from *P. flava*, the remaining infauna is few in both species and individuals, perhaps the most striking being the two snake-eels *Callechelys melanotaenia* Bleeker and *Leiuranus semicinctus* (Lay & Bennett). However, the surface burrowers *Strombus gibberulus gibbosus* (Röding) and *Rhinoclavis asper* are common, together with hermits, including *Calcinus elegans* (H. Milne Edwards) and *Aniculus aniculus* (Fabricius).

FAUNA OF THE SUBLITTORAL DEPOSITS

Nine dredge hauls of the well-sorted medium to coarse sands found over the reef-rim (Stations L1-L9) were taken in depths of 1-2 m and 11 of the poorly-sorted finer deposits covering the lagoon floor (Stations L10-L20) in depths of 1-6 m (see Fig.36). The species taken in these samples are listed in Table 16. It should be noted that the distributions of the chaetopterid species are wider than the records suggest since empty or fragmentary tubes were present in most samples but cannot be identified with certainty.

Many of the species recorded from the intertidal zone are also widely distributed throughout the lagoon. The commonest of these include *Glycera lancadivae*, *Nematonereis unicornis* (Grube), *Aonides oxycephala* (Sars), *Malacoceros indicus*, chaetopterid spp., *Dasybranchus caducus*, *Rhinoclavis asper*, *Strombus gibberulus gibbosus*, *Natica gaultieriana*, *Pupa sulcata* (Gmelin), *Atys cylindrica* and *Ptychodera flava*. Of the total of about 70 species dredged in the lagoon, at least 46 species (chiefly molluscs (31) and polychaetes (10)) are recorded only from the sublittoral zone but the majority of these are known only from one or two stations.

Excluding those taken intertidally, the commoner sublittoral species (i.e. those taken at 4 or more stations) are relatively few in number. Characteristic species of the coarser, reef-rim deposits are *Strombus mutabilis* Swainson and the cephalochordate *Asymmetron lucayanum* Andrews, whilst *Lioconcha ornata* (Dillwyn) and *Glossobalanus* sp. appear to be characteristic of the finer deposits. On the other hand, the bivalves *Tellinella staurella* (Lam.) and *Arcopagia* (*Pinguitellina*) *robusta* (Hanley) do not appear to be so restricted in their distribution, both species being widespread throughout the sublittoral of the lagoon.

DISCUSSION

As mentioned above, surveys of the soft-bottom lagoon communities of only a few of the remote atolls in the Central Pacific have been made. A major interest in such surveys in this region obviously lies in obtaining records for defining the eastern limits of the distribution pattern of many shallow-water Indo-West-Pacific species. Although this aspect is fairly well documented for some groups, for example, brachyuran decapods (see Forest & Guinot, 1962) and molluscs (see Ranson, 1967), many other groups remain poorly known. Whilst the present survey has contributed many records towards a preliminary check-list of the Cook Islands marine fauna (see Gibbs *et al*, 1975), the primary aim in carrying out a survey of the Aitutaki lagoon was to obtain an estimate of the species diversity of the soft-bottom community.

The species composition of the soft-bottom community on Aitutaki is given in Table 16; its composition by group is as follows:

Polychaeta	27	Gastropoda	31
Oligochaeta	1	Pelecypoda	13
Sipuncula	1	Echinodermata	4
Phoronida	1	Cephalochordata	1
Stomatopoda	2	Enteropneusta	2
Decapoda	20+	Teleostei	3

Thus, from these preliminary data, the soft-bottom macrofauna of the lagoon is estimated at a total of about 100 species. The number of species represented in each of the three main deposit zones, i.e. the intertidal sand flat of the mainland, the reef rim, and the lagoon floor, are given in Table 17. These data show that the intertidal flat has fewer species than either of the other two zones chiefly because of the paucity of mollusc species. However, the fact that only 10 mollusc species were discovered on the intertidal flat could be a result of many of the sand-dwelling molluscs being highly regarded as food by the islanders, as noted by Banner (1952) for Onotoa Atoll, Gilbert Islands. Further, it should be mentioned that a number of species, notably terebrids

and mitrids, represented in the Morgan Collection of mollusc shells (see Chapter 10 of this Bulletin) and collected at Aitutaki, were not found in the present survey.

Although data relating to species diversity and faunal composition of the soft-bottom benthos of other atoll lagoons are not available for comparison, several features of interest emerge in relating the present observations with those of the surveys of Tuamotu atolls. The most abundant molluscs on Aitutaki are Rhinoclavis asper, Strombus spp., Natica gaultieriana, Pupa sulcata, Tellinella staurella and Arcopagia (Pinguitellina) robusta; interestingly only the last-named species is included in the list of the 12 most abundant molluscs found by Salvat (1972) on Réao. On Réao, and other atolls (see Ranson, 1954; Salvat, 1967), Fragum fragum (L.) is the dominant mollusc, but on Aitutaki this species appears to be uncommon, only two live specimens being taken in the 20 dredge hauls. Also the Aitutaki fauna appears to lack any species of spatangoid: no specimens or traces of such forms as Rhinobrissus hemiasteroides A. Agassiz and Brissopsis luzonica (Gray) were discovered, although both of these species are common in the lagoon of Mururoa (Salvat & Renaud-Mornant, 1969). The widespread abundance of enteropneusts, particularly Ptychodera flava, except on the mainland shore, is a striking feature of the Aitutaki lagoon fauna: on other atolls that have been investigated this group appears to be less dominant. Whilst such differences in the relative abundance of species may be related to sedimentological processes and atoll structure (see Salvat, 1967), before comparative and regional analyses can be attempted, much faunistic data remains to be compiled both for individual atolls and atoll groups.

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I am most grateful to the Royal Society and the Royal Society of New Zealand for the opportunity to participate in the Cook Bicentenary Expedition in 1969. I would like to thank Dr D.R. Stoddart and Dr H.G. Vevers for much assistance in the field and also Mr E.W. Dawson (Expedition Leader) and other Expedition members for their help. This paper could not have been completed without the material assistance of many group experts who have kindly identified specimens: my thanks are due to Dr W.O. Cernohorsky (Mollusca), Dr J.C. Yaldwyn (Crustacea), Miss A.M. Clark (Ophiuroidea), Dr F.W.E. Rowe (Holothuroidea), Dr S.J. Edmonds (Sipuncula), Dr J.H. Wickstead (Asymmetron), Prof. C. Burdon-Jones (Enteropneusta) and Dr G. Palmer (Teleostei).

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Table 16. Aitutaki lagoon: list of species occurring in samples taken at littoral Stations 1-10 between high and low water levels and in samples dredged at Stations L1-L20 in depths of 1-6m (see Fig. 36)

SPECIES STATION	1	2	3	4	5	6	7	8	9	10	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
Polychaeta																														
Paleanotus debilis (Grube)										+																				
Eurythoë complanata (Pallas)															+															
Gyptis capensis (Day)										+		+		+												+				
Typosyllis regulata Imajima												+			+															+
Ceratonereis vaipekae Gibbs						+		+																						
Glycera lancadivae Schmarda	+	+	+		+				+			+	+	+		+		+		+	+	+	+	+	+	+	+	+	+	+
Marphysa macintoshi Crossland	+		+		+		+	+																						
Nematonereis unicornis (Grube)										+	+	+	+		+														+	+
Aonides oxycephala (Sars)												+			+		+										+			
Malacoceros indicus (Fauvel)	+	+	+	+	+	+	+	+	+																+	+	+	+		
Prionospio malmgreni Claparède																+		+								+		+		
Scolelepis aitutakii Gibbs										+																+			+	
Scolelepis squamata saipanensis (Hartman)	+	+		+	+																									
Spio filicornis (Müller)				+																										
Poecilochaetus tropicus Okuda																										+			+	
Mesochaetopterus sagittarius (Claparède)	+			+	+				+			+				+														
Phyllochaetopterus brevitentaculata Hart-Sch.					+					+	+	+	+		+	+				+			+							
Phyllochaetopterus elioti Crossland					+				+		+				+															
Phyllochaetopterus verrilli Treadwell										+	+	+			+	+					+								+	+
Spiochaetopterus costarum (Claparède)			+		+				+											+				+		+				
Armandia melanura Gravier	+	+	+	+	+																									
Polyophthalmus pictus (Dujardin)																					+							+		
Dasybranchus caducus (Grube)	+		+	+	+				+	+													+		+	+		+		
Myriochele haplosoma Gibbs																												+		+

Table 16 continued

SPECIES STATION	1	2	3	4	5	6	7	8	9	10	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
Myriochele sp.																												+		
Branchiomma cingulata (Grube)												+																		
Branchiomma picta (McIntosh)																					+									
Oligochaeta																														
Pontodrilus matsushimensis Iizuka					+	+	+																							
Sipuncula																														
Siphonosoma cumanense (Keferstein)					+																									
Phoronida																														
Phoronopsis harmeri Pixell									+			+	+															+		+
Crustacea[1]																														
Amphipod sp(p).											+			+				+												
Lysiosquilla maculata Fabricius					(+)	(+)			(+)																					
Heterosquilla sp.									+																					
Alpheus crassimanus Heller					+																									
Alpheid sp.															+															
Callianassa sp.					+																									
Aniculus aniculus (Fabricius)										+																				
Calcinus elegans (H. Milne Edwards)										+																				
Calcinus latens (Randall)					+																									
Clibanarius humilis (Dana)					+																									
Pagurid sp(p).													+	+																
Calappa hepatica (L.)					+				+																					
Macrophthalmus convexus Stimpson			+	+	+	+	+	+																						

Table 16 continued

SPECIES STATION	1	2	3	4	5	6	7	8	9	10	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
Ocypode laevis Dana			+	+																										
Uca tetragonon (Herbst)			+	+	+	+	+	+																						
Brachyuran sp(p).											+				+															
Mollusca																														
Philippia radiata (Rödlng)[3]																					+									
Cerithium columna Sowerby															+				+		+									
Cerithium variegatum Quoy & Gaim.					+		+																							
Rhinoclavis asper (L.)					+					+	+	+	+		+	+			+	+										+
Bittium sp.[3]																														+
Triphora pavimenta (Laseron)																			+											
Strombus gibberulus gibbosus (Röd.)										+	+					+		+	+		+									
Strombus maculatus Sowerby															+													+		
Strombus mutabilis Swainson											+	+		+	+				+											
Natica areolata Recluz																														+
Natica bougei Sowerby											+	+														+				
Natica gualtieriana Recluz					+																+		+	+	+		+	+	+	
Cypraea annulus obvelata (Lam.)													+																	
Cypraea moneta L.					+																									
Engina histrio (Reeve)																			+											
Engina lauta (Reeve)																			+											
Nassarius graniferus (Kiener)																					+									
Vexillum tusum (Reeve)[3]																														+
Gibberula sp. cf. G.ros (Reeve)[3]																														+

Table 16 continued

SPECIES STATION	1	2	3	4	5	6	7	8	9	10	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
Eucithara pulchella (Reeve)													+																	
Clavus sp.[3]																				+										
Terebra affinis Gray													+																	
Pupa sulcata (Gmelin)										+						+			+		+	+					+	+	+	+
Bulla punctulata A.Adams															+															
Atys cylindrica (Helbling)					+										+	+		+		+	+	+	+				+			+
Atys naucum (L.)											+																			
Cylichna dentifera A.Adams[3]																+														
Pyramidella acus (Gmelin)					+				+		+		+																	
Pyramidella terebellum (Müller)																				+										
Otopleura auriscati (Holten)														+																
Stylocheilus longicauda (Quoy & Gaim.)															+															
Modiolus auriculatus (Krauss)					+							+																		
Fragum fragum (L.)																				+						+				
Fragum unedo (L.)																						+								+
Codakia punctata (L.)																			+											
Codakia divergens (Philippi)										+																				
Anodontia edentula (L.)																			+											
Lioconcha ornata (Dillwyn)																							+	+		+	+		+	
Gafrarium pectinatum (L.)					+																							+		
Asaphis violascens (Forskål)					+	+			+																					
Gari gari (L.)[3]																						+						+		+
Tellinella staurella (Lam.)											+					+			+	+		+	+						+	
Quidnipagus palatum Iredale				+	+																									
Arcopagia robusta (Hanley)											+			+		+	+				+	+	+		+	+		+	+	+

Table 16 continued

SPECIES / STATION	1	2	3	4	5	6	7	8	9	10	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
Echinodermata																														
Amphipholis squamata (Delle Chiaje)															+							+						+	+	+
Amphiodia sp. aff. A. individua Mort.																												+		
Chiridota hawaiiensis Fisher																													+	+
Holothuria atra Jaeger					+					+																				
Hemichordata																														
Ptychodera flava Eschscholtz									+	+	+	+	+		+	+	+		+	+	+	+	+	+	+	+	+		+	+
Glossobalanus sp.																							+	+	+	+	+	+	+	+
Cephalochordata																														
Asymmetron lucayanum Andrews													+	+	+	+														
Teleostei																														
Leiuranus semicinctus (Lay & Benn.)										+					+															
Callechelys melanotaenia Bleeker										+																				
Echelid sp.																					+									

[1] The portunid and grapsid crabs, which probably range widely within the lagoon have been omitted: these are *Thalamita admete* (Herbst), *Thalamita crenata* (H. Milne Edwards), *Scylla serrata* (Forskål), *Metopograpsus thukuhar* (Owen) and *Percnon planissimum* (Herbst).

[2] Burrows seen but specimens not collected.

[3] Mollusc species recorded only from empty shells.

Table 17. Comparison of the number of species represented in the three main deposit zones of the lagoon on Aitutaki

Zone / Group	Intertidal flat HWM-LWM Stations 3-8	Reef rim LWM-2m depth Stations 10, L1-L9	Lagoon floor 1-6m depth Stations L10-L20
Polychaeta	12	15	17
Crustacea[1]	9	6	1
Mollusca[2]	10	27	23
Other	3	7	7
Total	34	55	48

[1]Excluding portunids and grapsids - see Table 1

[2]Including trace (shell only) species

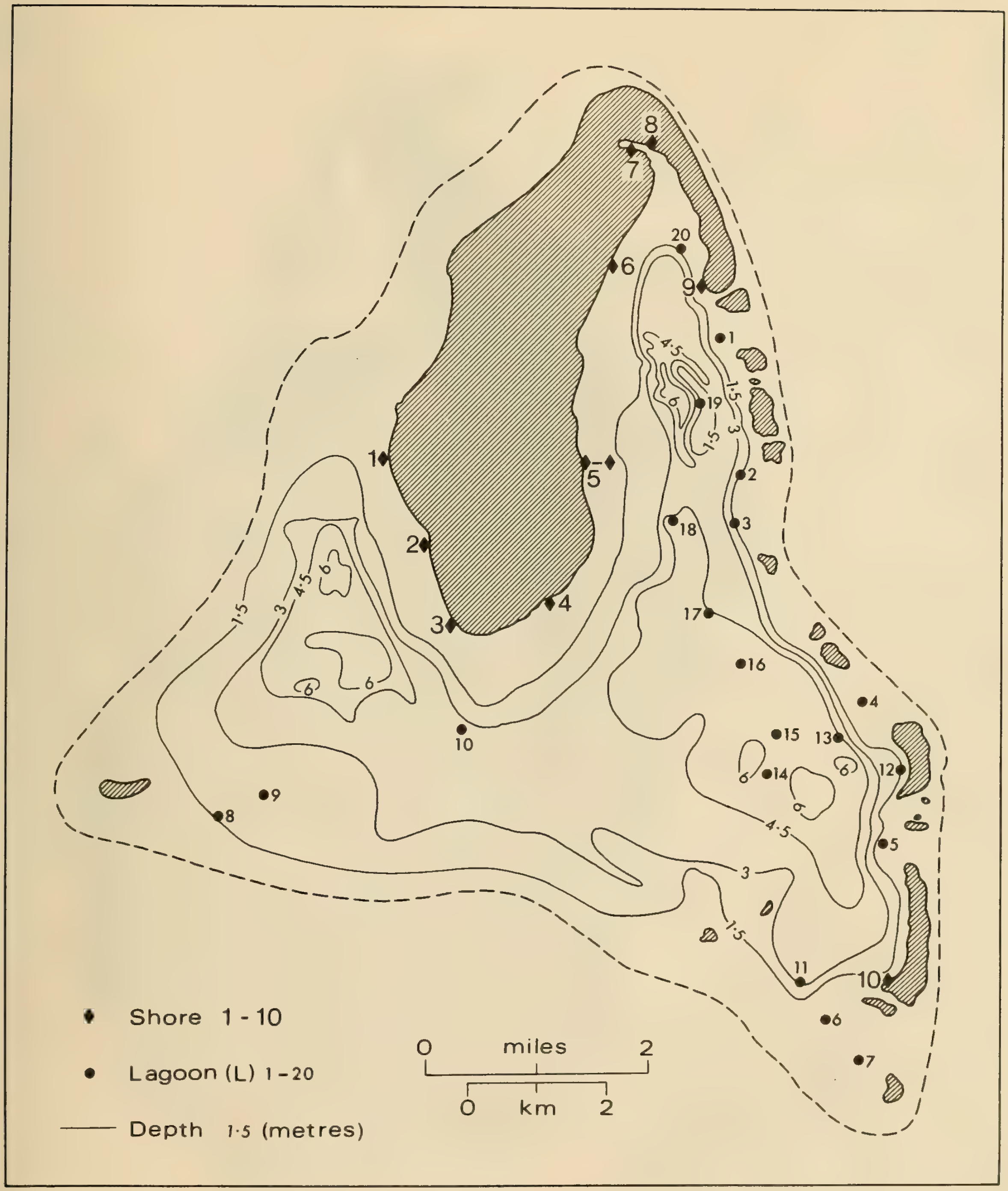

Figure 36. Map of Aitutaki showing lagoon bathymetry and location of sampling stations

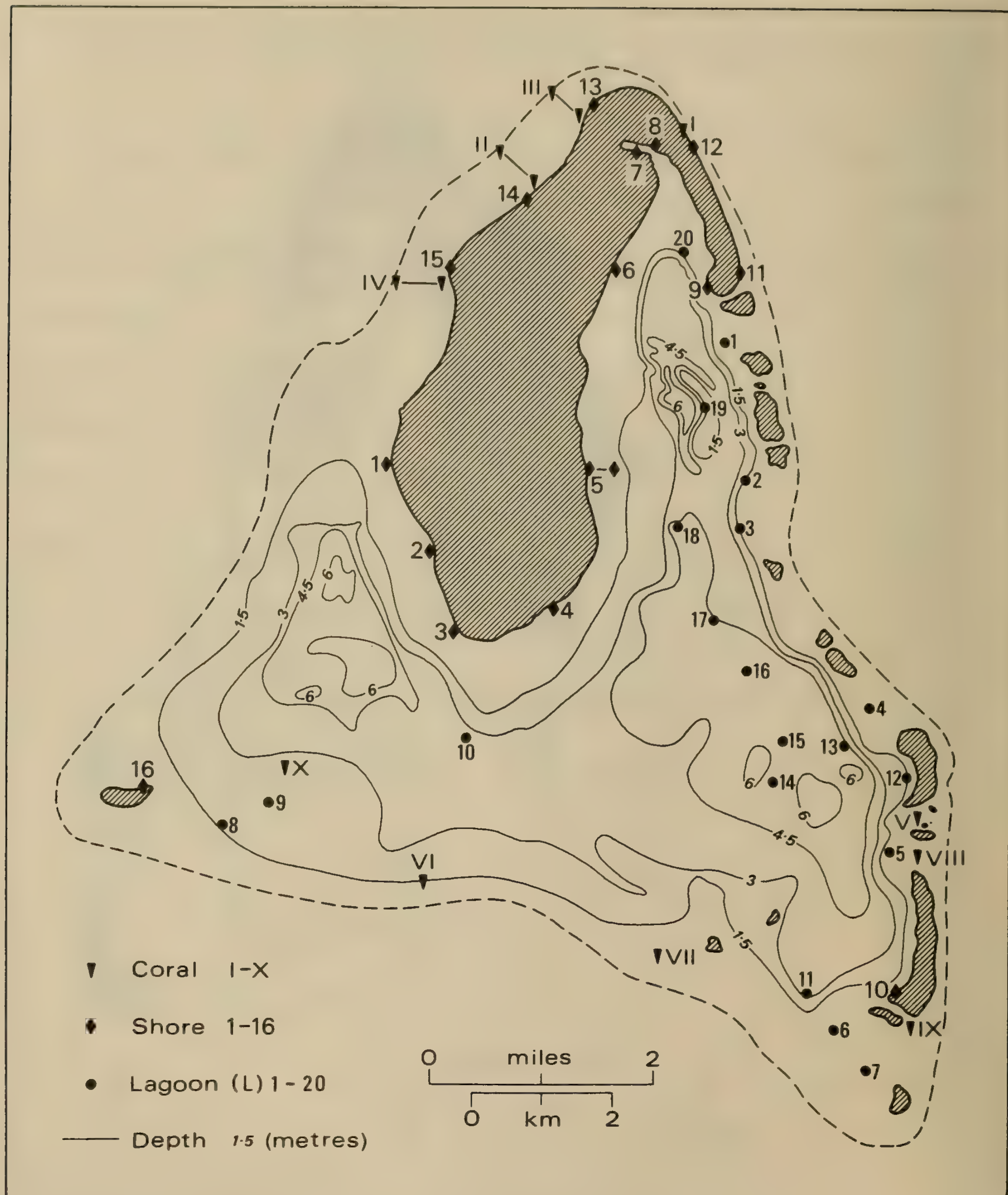

Figure 37. Map of Aitutaki showing positions of shore stations 1-16, dredge stations L1-L20, and coral collection areas I-X.

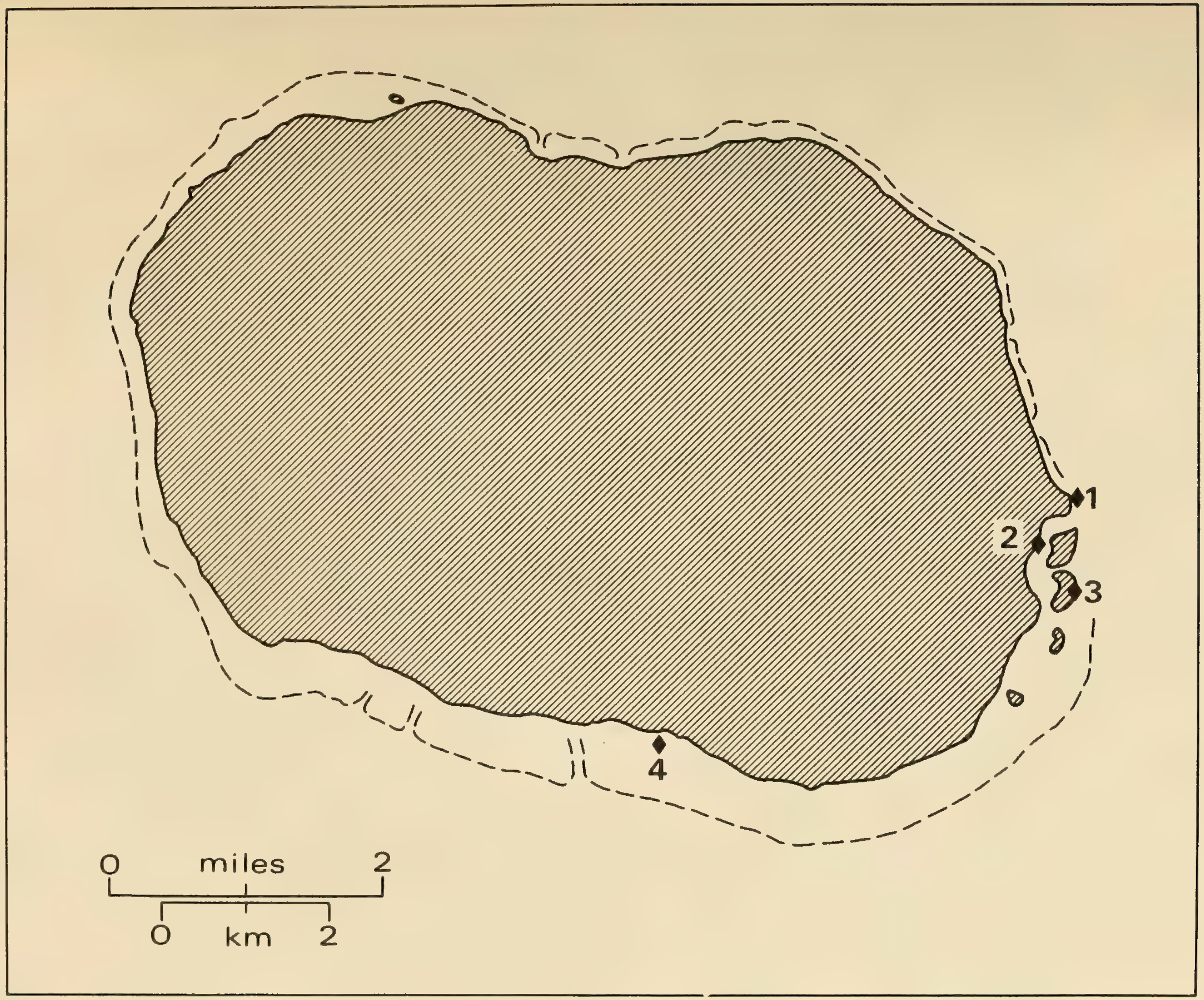

Figure 38. Map of Rarotonga showing locations of shore stations R1-R4

9. MARINE FAUNA OF THE COOK ISLANDS: CHECK-LIST OF SPECIES COLLECTED DURING THE COOK BICENTENARY EXPEDITION IN 1969

P.E. Gibbs, H.G. Vevers and D.R. Stoddart

INTRODUCTION

As part of the Cook Bicentenary Expedition in 1969, various aspects of the marine communities of the reef and lagoon environments on Aitutaki and Rarotonga in the southern Cook Islands were investigated. Descriptions of these surveys, carried out between 21 August and 26 September, and the study areas are given in Gibbs, Stoddart & Vevers (1971), Gibbs (1975) and Stoddart (1975a, 1975b). Some of the material resulting from these studies has already been described (see Gibbs, 1971; Pillai & Stoddart, In press; Stoddart & Pillai, 1973) but since it is doubtful whether all of the Expedition material will be utilized and/or recorded in future publications, it was considered advisable to bring together all of the species records in the form of a preliminary check-list of the marine fauna which would serve as a basis for further faunistic work in the Cook Islands.

This check-list of the marine fauna is based solely on the collections made on Aitutaki and Rarotonga during the 1969 Expedition: no attempt has been made to include species recorded previously from the Cook Islands although here attention may be drawn to the papers of Banner & Banner (1967), McKnight (1972) and Devaney (1973) who have dealt with the alpheid shrimps and echinoderms, and to the lists of corals, sipunculids, molluscs, crabs, echinoderms and fishes from Manihiki Atoll (in Bullivant and McCann, 1974). This check-list is, to a certain extent, selective in that because of the limited time available efforts were directed towards obtaining comprehensive collections of certain groups or communities and, as a result, the scleractinians and echinoderms as well as the macrofauna inhabiting the lagoon deposits on Aitutaki are well represented. However, apart from the corals and echinoderms, the reef fauna is known only from general collections. Consequently, the molluscs for example, with 92 species recorded, are probably poorly represented, considering that about 260 species are known from French Oceania (see Ranson, 1967) and that the atoll of Raroia (Tuamotus) alone may support over 600 species (Morrison, 1954). However the Expedition collection of molluscs is supplemented by the Morgan collection of Cook Islands mollusc shells now housed by the Cook Islands Library and Museum at Rarotonga (see Chapter 10 of this Bulletin). This valuable collection, containing over 200 species, deserves to be documented more fully by a group expert.

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We wish to thank the Royal Society and the Royal Society of New Zealand for the opportunity to take part in the Cook Bicentenary Expedition. This check-list could not have been compiled without the kind assistance of many group experts: for identifying material in the Expedition collections we are most grateful to C.S.G. Pillai (Scleractinia), S.J. Edmonds (Sipuncula), C.C. Emig (Phoronopsis), J.C. Yaldwyn (most Crustacea, Xanthidae assisted by J.S. Garth), R.S.K. Barnes (Macrophthalmus), R.W. Ingle (Crustacea deposited in British Museum (Nat. Hist.)), W.O. Cernohorsky (most Mollusca), J.D. Taylor (Mollusca deposited in Brit. Mus. (Nat. Hist.)), A.M. Clark (Asteroidea, Ophioroidea, Echinoidea), F.W.E. Rowe (Holothuroidea), C. Burdon-Jones (Enteropneusta), J.H. Wickstead (Asymmetron) and G. Palmer (Teleostei).

The Expedition collections are composed of nearly 300 species comprising the following groups:

Scleractinia	57	Asteroidea	3
Polychaeta	38	Ophiuroidea	9
Oligochaeta	1	Echinoidea	2
Sipuncula	4	Holothuroidea	14
Phoronida	1	Hemichordata	2
Stomatopoda	3	Cephalochordata	1
Decapoda	55+	Teleostei	14
Gastropoda	71		
Pelecypoda	20	Total	295+
Cephalopoda	1		

This material has been deposited in the British Museum (Natural History) and the National Museum, Wellington. Most specimens of the Crustacea and Mollusca are placed in the National Museum, the remainder in the British Museum (Nat. Hist.): in the check-lists of these two groups, species deposited in the British Museum (Nat. Hist.) collections are marked * and where both museums have specimens the species is marked +. The collections of all other groups are deposited in the British Museum (Nat. Hist.).

In the check-list, for each species the stations at which specimens were taken are given. The positions of the stations on Aitutaki are shown in Fig. 37 and on Rarotonga in Fig. 38. The main habitats investigated at these stations are as follows

Aitutaki:	Stations	1 - 10	intertidal lagoon sand flat
		11 - 12	outer reef platform
		13 - 15	outer reef-chiefly coral heads
		16	beach rock
		L1 - L9	medium to coarse sand, 1-2m depth (dredge)
		L10 - L20	silty sand, 1-6m depth (dredge)

Rarotonga: Stations R1 + R3 : outer reef platform
R2 + R4 : intertidal sand flat

In addition to the above, corals were collected at 10 localities on Aitutaki (Fig. 1, Areas 1 - X) and at Station R3 on Rarotonga.

Check-list of species

Coelenterata

Scleractinia

The following coral species were collected in shallow water (0-3m depth):

Astrocoeniidae	
Stylocoeniella armata (Ehrenberg)	X
Thamnasteriidae	
Psammocora contigua (Esper)	R3
Psammocora (Plesioseris) haimeana Milne-Edwards & Haime	I II
Pocilloporidae	
Pocillopora brevicornis Lam.	I
Pocillopora damicornis (L.)	II IV V R3
Pocillopora ligulata Dana	II III
Pocillopora meandrina Dana var. nobilis Verrill	I IV VII R3
Pocillopora verrucosa (Ellis & Solander)	IV
Acroporidae	
Acropora corymbosa (Lam.)	R3
Acropora diversa (Brook)	R3
Acropora formosa (Dana)	V
Acropora humilis (Dana)	R3
Acropora hyacinthus (Dana)	VI
Acropora otteri Crossland	II
Acropora paniculata Verrill	II
Acropora rosaria (Dana)	II V
Acropora rotumana (Gardiner)	I
Acropora squarrosa (Ehrenberg)	V
Acropora surculosa (Dana)	I R3
Acropora variabilis Klunzinger	II
Astreopora listeri Bernard	I III
Montipora ehrenbergii Verrill	II IV
Montipora elschneri Vaughan	R3
Montipora gracilis Klunzinger	II
Montipora spumosa (Lam.)	IV
Montipora venosa (Ehrenberg)	III IV
Montipora sp. (?nov.)	II

Agariciidae	
Pavona varians Verrill	
Fungiidae	
Fungia (Pleuractis) paumotensis Stutchbury	X
Fungia (Pleuractis) scutaria Lam.	VI X
Fungia (Verrillofungia) concinna Verrill	II III VI VIII X
Herpolitha limax (Esper)	VI
Poritidae	
Porites lutea Milne-Edwards & Haime	I II III IV VII R3
Faviidae	
Cyphastrea chalcidicum (Forskal)	R3
Cyphastrea serailia (Forskal)	VI
Echinopora horrida Dana	VI
Favia favus (Forskal)	I VI VIII
Favia pallida (Dana)	VIII R3
Favia stelligera (Dana)	II VI VII X
Favites abdita (Ellis & Solander)	IX
Favites acuticollis (Ortmann)	I
Favites flexuosa (Dana)	VIII
Goniastrea benhami Vaughan	
Goniastrea pectinata (Ehrenberg)	III IV X
Hydnophora exesa (Pallas)	VII VIII
Hydnophora microconos (Lam.)	I II III IV R3
Leptastrea purpurea (Dana)	R3
Leptastrea transversa Klunzinger	III R3
Leptoria phrygia (Ellis & Solander)	I II III IV R3
Platygyra lamellina Ehrenberg	III IV VI R3
Plesiastrea lilli Wells	X
Plesiastrea versipora (Lam.)	I IV VIII IX R3
Oculinidae	
Galaxea clavus (Dana)	IV
Galaxea fascicularis (L.)	II IV
Mussidae	
Acanthastrea echinata (Dana)	I VI R3
Lobophyllia corymbosa (Forskal)	I III IV VI R3
Dendrophylliidae	
Turbinaria sp. cf. *veluta* Bernard	R3

Annelida

Polychaeta

Aphroditidae	
Gastrolepidia clavigera Schmarda	12 R1
Hololepidella nigropunctata (Horst)	12 R1

Palmyridae	
Paleanotus debilis (Grube)	10
Amphinomidae	
Eurythoë complanata (Pallas)	12 L5 R1
Phyllodocidae	
Phyllodoce pruvoti Fauvel	R1
Phyllodoce (Anaitides) madeirensis Langerhans	12
Hesionidae	
Gyptis capensis (Day)	10 L2 L4 L16
Hesione splendida Savigny	R1 R3
Leocrates chinensis Kinberg	R1
Syllidae	
Typosyllis regulata Imajima	L2 L5 L20 R3
Nereidae	
Ceratonereis vaipekae Gibbs	6 8
Perinereis cultrifera (Grube)	11 R3
Perinereis jascooki Gibbs	R3
Perinereis nigropunctata (Horst)	R3
Pseudonereis variegata (Grube)	R3
Glyceridae	
Glycera lancadivae Schmarda	1 2 3 5 9 11 L2 L3 L4 L6 L8 L10 L11 L12 L13 L14 L15 L16 L17 L18 L19 L20 R3 R4
Eunicidae	
Marphysa macintoshi Crossland	1 3 5 7 8
Nematonereis unicornis (Grube)	10 L1 L2 L3 L5 L19 L20
Spionidae	
Aonides oxycephala (Sars)	L2 L5 L7 L17
Malacoceros indicus (Fauvel)	1 2 3 4 5 6 7 8 9 L15 L16 L17 L18 R2 R4
Prionospio malmgreni Claparède	L6 L8 L16 L18
Scolelepis (Scolelepis) aitutakii Gibbs	10 L16 L19
Scolelepis (Scolelepis) squamata saipanensis (Hartman)	1 2 4 5
Spio filicornis (Muller)	4
Trochochaetidae	
Poecilochaetus tropicus Okuda	L16 L19

Chaetopteridae	
<u>Mesochaetopterus</u> <u>sagittarius</u> (Claparède)	1 5 9 L2 L6 R1 R4
<u>Phyllochaetopterus</u> <u>brevitentaculata</u> Hartmann-Schröder	5 10 L1 L2 L3 L5 L6 L10 L13
<u>Phyllochaetopterus</u> <u>elioti</u> Crossland	5 9 L1 L5
<u>Phyllochaetopterus</u> <u>verrilli</u> Treadwell	10 L1 L2 L5 L6 L11 L19 L20
<u>Spiochaetopterus</u> <u>costarum</u> <u>costarum</u> (Claparède)	3 5 9 L10 L14 L16 R4
Opheliidae	
<u>Armandia</u> <u>melanura</u> Gravier	1 2 3 4 5
<u>Polyophthalmus</u> <u>pictus</u> (Dujardin)	L11 L18
Capitellidae	
<u>Dasybranchus</u> <u>caducus</u> (Grube)	1 3 4 5 9 10 L13 L15 L16 L18 R2 R4
Oweniidae	
<u>Myriochele</u> <u>haplosoma</u> Gibbs	L18 L20
<u>Myriochele</u> sp.	L18
Sabellidae	
<u>Branchiomma</u> <u>cingulata</u> (Grube)	L2
<u>Branchiomma</u> <u>picta</u> (McIntosh)	L11 L19
<u>Sabellastarte</u> <u>sanctijosephi</u> (Gravier)	R1

Oligochaeta

Megascolecidae	
<u>Pontodrilus</u> <u>matsushimensis</u> Iizuka	5 6

Sipuncula

Sipunculidae	
<u>Siphonosoma</u> (<u>Damosiphon</u>) <u>cumanense</u> (Keferstein)	5 11 R3
Aspidosiphonidae	
<u>Aspidosiphon</u> <u>elegans</u> (Chamisso & Eysenhardt)	11
Phascolosomatidae	
<u>Phascolosoma</u> (<u>Antillesoma</u>) <u>asser</u> (Selenka & de Man)	12
<u>Phascolosoma</u> (<u>Phascolosoma</u>) <u>albolineatum</u> Baird	R3

Phoronida

<u>Phoronopsis</u> <u>harmeri</u> Pixell	9 L2 L3 L18 L20

Crustacea

Stomatopoda

	Taxon	Stations		
*	*Gonodactylus chiragra* (Fabricius)	14		
	Lysiosquilla maculata (Fabricius)	9		
	Heterosquilla sp. (small)	9		

Decapoda

Caridea

	Taxon	Stations		
	Hippolytidae			
*	*Thor* sp.	14		
	Alpheidae			
	Alpheus crassimanus Heller	5		
	Alpheus pacificus Dana	5		
+	*Alpheus* sp(p).	13	14	R3
*	*Arete* sp.	14		
	Athanas djiboutensis Coutiere	5		
	Palaemonidae			
*	*Coralliocaris* sp.	14		
	Gnathophyllidae			
*	*Gnathophyllum* sp.	14		

Thalassinidea

	Taxon	Stations		
	Callianideidae			
	Callianidea typa H. Milne Edwards	R3		
	Callianassidae			
	Callianassa (*Callichirus*) sp. near *C. placida* de Man	5		

Paguridea

	Taxon	Stations		
	Coenobitidae			
	Coenobita perlata H. Milne Edwards	10	16	
	Coenobita rugosa H. Milne Edwards	10		
	Paguridae			
	Aniculus aniculus (Fabricius)	10		
	Calcinus elegans (H. Milne Edwards)	10	12	
	Calcinus herbstii de Man	16		
	Calcinus latens (Randall)	5		
	Clibanarius humilis (Dana)	5		
	Dardanus deformis (H. Milne Edwards)	10		
	Dardanus scutellatus (H. Milne Edwards)	16		
+	Pagurid spp.	12	13	14

Galatheidea

Galatheidae	
*Galatheid sp(p).	13 14
Porcellanidae	
<u>Petrolisthes</u> <u>lamarkii</u> (Leach)	R3

Oxystomata

Calappidae	
<u>Calappa</u> <u>hepatica</u> (L.)	5 9

Oxyrhyncha

Majidae	
*Majid sp.	13 14

Brachyrhyncha

Portunidae	
<u>Scylla</u> <u>serrata</u> (Forskål)	northern lagoon
<u>Thalamita</u> <u>admete</u> (Herbst)	5
<u>Thalamita</u> <u>crenata</u> (H. Milne Edwards)	5 6 9
<u>Thalamita</u> <u>edwardsi</u> Borradaile	R3
* <u>Thalamita</u> sp.	13
Atelecyclidae	
<u>Kraussia</u> <u>rugulosa</u> (Krauss)	R3
Xanthidae	
<u>Chlorodiella</u> <u>cytherea</u> (Dana)	R3
<u>Eriphia</u> <u>sebana</u> (Shaw & Nodder)	10
<u>Leptodius</u> <u>gracilis</u> (Dana)	11 R3
<u>Leptodius</u> <u>leptodon</u> Forest & Guinot	11 R3
<u>Leptodius</u> <u>sanguineus</u> (H. Milne Edwards)	11 R3
<u>Liomera</u> <u>bella</u> (Dana)	R3
<u>Liomera</u> <u>laevis</u> (A. Milne Edwards)	R3
<u>Lydia</u> <u>annulipes</u> (H. Milne Edwards)	R3
<u>Pilodius</u> <u>areolatus</u> (H. Milne Edwards)	R3
<u>Pilodius</u> <u>scabriculus</u> Dana	R3
<u>Pseudozius</u> <u>caystrus</u> (Adams & White)	11 R3
<u>Xanthias</u> <u>lamarkii</u> (A. Milne Edwards)	R3
*Xanthid sp(p.).	12 13 14 15
Ocypodidae	
<u>Macrophthalmus</u> (<u>Macrophthalmus</u>) <u>convexus</u> Stimpson	3 4 5 6 7 R2
<u>Ocypode</u> <u>laevis</u> Dana	3 4
<u>Uca</u> <u>tetragonon</u> (Herbst)	3 4 6 7 R2

Grapsidae
Cyclograpsus sp. cf. C. intermedium Ortmann 11
Grapsus tenuicrustatus (Herbst) 10
Metopograpsus thukuhar (Owen) 5 R3
Pachygrapsus minutus A. Milne Edwards R3
Pachygrapsus plicatus (H. Milne Edwards) R3
Pachygrapsus sp. 15
Percnon planissimum (Herbst) 5

Gecarcinidae
\+ Cardisoma carnifex (Herbst) 6 R1

Hapalocarcinidae
*Hapalocarcinid sp. 13

Mollusca

Gastropoda

" indicates species known only from empty shells

Trochidae
\+ Trochus (Tectus) niloticus L. 12 15

Turbinidae
\+ Astraea (Australium) rhodostoma Lam. 12 R1
Turbo (Marmarostoma) argyrostomus L. 12
* Turbo (Marmarostoma) setosus Gmelin 12

Neritidae
Nerita plicata L. 2 16

Phenacolepadidae
Phenacolepis tenuisculpta Thiele R3

Vermetidae
Vermetus maximus (Sowerby) 12

Planaxidae
Planaxis (Angiola) lineatus (da Costa) (= ineptus Gould) 11

Cerithiidae
"Bittium sp. L20
Cerithium columna Sowerby 16 L5 L9 L11
* Cerithium nodulosus (Bruguière) 13
Cerithium (Clypeomorus) rugosum Wood 2 16
Cerithium (Clypeomorus) variegatum Quoy & Gaimard 5 7

Cerithium (Conocerithium) egenum Gould	12
Cerithium (Semivertagus) nesioticum Pilsbry & Vanatta	12
Rhinoclavis asper L.	5 10 L1 L2 L3 L5 L6 L9 L10 L20
Triphoridae	
Triphora pavimenta (Laserow)	L9
Architectonicidae	
"Philippia radiata (Röding)	L11
Vanikoridae	
* Vanikoro sp.	12
Hipponicidae	
Hipponix conicus (Schumacher)	12
Females parasitic on Astraea rhodostoma and Turbo argyrostomus	
Strombidae	
Strombus gibberulus gibbosus (Röding)	10 L1 L6 L8 L9 L11
Strombus maculatus Sowerby	L5 L18
Strombus mutabilis Swainson (juveniles)	L1 L2 L4 L5 L9
Naticidae	
Natica areolata Recluz	L20
Natica bougei Sowerby	L1 L2 L16
Natica gualtieriana Reclux (= marochiensis of authors - non Gmelin)	5 L11 L13 L14 L15 L17 L18 L19
Cypraeidae	
+ Cypraea (Erosaria) caputserpentis L.	12 13
* Cypraea (Erosaria) helvola L.	R1
* Cypraea (Luria) isabella L.	R1
Cypraea (Mauritia) maculifera (Schilder)	12
Cypraea (Monetaria) annulus obvelata Lam.	L3
+ Cypraea (Monetaria) moneta L.	5 12 13 16
Cymatiidae	
Cymatium nicobaricum (Röding) (juvenile)	16
* Septa pilearis (L.)	13
Muricidae	
+ Drupa morum Röding	12
Drupa ricinus (L.)	12

	Drupina grossularia (Röding)	12
	Morula granulata (Duclos)	16
+	Morula uva (Röding)	12 14
	Thais armigera (Link)	12
	Magilidae	
	Coralliophila violacea (Kiener)	12
	Magilus antiquus (Montfort)	12
	Pyrenidae	
*	Pyrene sp. cf. spiculus Duclos	14
	Buccinidae	
*	Cantharus sp. (juvenile)	14
	Engina (Enginopsis) histrio (Reeve)	L9
	Engina (Enginopsis) lauta (Reeve)	L9
	Nassariidae	
	Nassarius graniferus (Kiener)	L11
	Fasciolariidae	
+	Peristernia nassatula (Lam.)	12 14
	Mitridae	
*	Mitra stictica (Link)	R1
	Mitra (Strigatella) litterata (Lam.)	16
	"Vexillum (Pusia) tusum (Reeve)	L20
	Marginellidae	
	"Gibberula sp. cf. ros (Reeve)	L20
	Conidae	
*	Conus catus Hwass	R1
+	Conus chaldaeus (Röding)	12 R1
+	Conus ebraeus L.	12 16 R1
*	Conus lividus Hwass	R1
	Conus miliaris Hwass	12
	Conus sponsalis Hwass	12
	Turridae	
	"Clavus sp.	L10
	Eucithara pulchella (Reeve)	L3
	Terebridae	
	Terebra affinis Gray	L3
	Acteonidae	
	Pupa sulcata (Gmelin)	10 L6 L9 L11 L12 L17 L18 L19 L20
	Bullidae	
	Bulla punctulata A. Adams	L5

Atyidae	
Atys cylindrica (Helbling)	5 L5 L6 L8 L10 L11 L12 L13 L17 L20
Atys naucum (L.)	L1
Scaphandridae	
"Cylichna (Diniatys) dentifera A. Adams	L6
Pyramidellidae	
Otopleura auriscati (Holten)	L4
Pyramidella acus (Gmelin)	5 9 L2 L4
Pyramidella terebellum (Müller)	L10
Aplysiidae	
Stylocheilus longicauda (Quoy & Gaimard)	L5
Hexabranchidae	
Hexabranchus marginatus (Quoy & Gaimard)	5 (stranded)

Pelecypoda

Arcidae	
Arca arabica Philippi	12
Mytilidae	
Modiolus auriculatus (Krauss)	5 L2
* Lithophaga sp.	13
Pteriidae	
* Pinctada sp.	13
Pinnidae	
* Pinna muricatum L.	R1
Lucinidae	
Anodontia edentula (L.)	L9
Codakia punctata (L.)	L9
Codakia (Epicodakia) divergens (Philippi)	10
Chamidae	
Chama iostoma (Conrad)	12
Cardiidae	
Fragum fragum (L.)	L9 L10 L16
Fragum unedo (L.)	L12 L20
Tridacnidae	
+ Tridacna (Chametrachea) maxima (Röding)	12 13

Veneridae	
Gafrarium pectinatum (L.)	5 L18
* *Gafrarium* sp.	14
Lioconcha ornata (Dillwyn)	L13 L14 L16 L17 L19
Sanguinolariidae	
Asaphis violascens (Forskål)	5 6 9
"*Gari gari* (L.)	L12 L18 L20
Tellinidae	
Arcopagia (*Pinguitellina*) *robusta* (Hanley)	L1 L4 L6 L7 L11 L12 L13 L15 L16 L18 L19 L20
Quidnipagus palatum Iredale	4 5
Tellinella staurella (Lam.)	L2 L6 L9 L10 L12 L13 L19

Cephalopoda

Octopodidae	
Octopus sp. (large)	12

Echinodermata

Asteroidea

Ophidiasteridae	
Linckia multifora (Lam.)	R3
Asteropidae	
Asteropsis carinifera (Lam.)	R1
Acanthasteridae	
Acanthaster planci (L.)	12 II IV

Ophiuroidea

Amphiuridae	
Amphiodia sp. cf. *individua* Mortensen	L18
Amphipholis squamata (Delle Chiaje)	L5 L12 L18 L19 L20 R1
Ophiactidae	
Ophiactis savignyi Müller & Troschel	14
Ophiotrichidae	
Macrophiothrix longipeda (Lam.)	12 R1
Ophiocomidae	
Ophiarthrum elegans Peters	12 R1 R3
Ophiocoma dentata Müller & Troschel	12 R1
Ophiocoma erinaceus Müller & Troschel	12 13

Ophiocoma pica Müller & Troschel	12
Ophiocomella sexradia (Duncan)	13 14

Echinoidea

Echinometridae	
Echinometra mathaei (de Blainville)	12 13 R1
Heterocentrotus mammillatus (L.)	12

Holothuroidea

Holothuriidae	
Actinopyga mauritiana (Quoy & Gaimard)	13 R1
Holothuria (*Halodeima*) *atra* Jaeger	5 10 R1
Holothuria (*Lessonothuria*) *pardalis* Selenka	R3
Holothuria (*Mertensiothuria*) *leucospilota* Brandt	12 R1
Holothuria (*Mertensiothuria*) *pervicax* Selenka	R1
Holothuria (*Platyperona*) *difficilis* Semper	R1
Holothuria (*Semperothuria*) *cinerascens* (Brandt)	12 R1
Holothuria (*Thymiosycia*) *hilla* Lesson	12 R1
Holothuria (*Thymiosycia*) *impatiens* (Forskål)	13 R1
Stichopodidae	
Stichopus chloronotus Brandt	14 R1
Stichopus horreus Selenka	R1
Stichopus variegatus Semper	13
Synaptidae	
Euapta godeffroyi (Semper)	R1
Chiridotidae	
Chiridota hawaiiensis Fisher	11 L19 L20 R3

Hemichordata

Enteropneusta

Ptychodera flava Eschscholtz	9 10 L1 L2 L3 L5 L6 L7 L9 L10 L11 L12 L13 L14 L15 L16 L17 L19 L20
Glossobalanus sp.	L13 L14 L15 L16 L17 L18 L19 L20

Cephalochordata

Asymmetron lucayanum Andrews	L3	L4	L5	L6

Pisces

Teleostei

Congridae		
Conger cinereus cinereus Rüppell	R1	
Echelidae		
Echelid sp.	L11	
Ophichthyidae		
Callechelys melanotaenia Bleeker	10	
Leiuranus semicinctus (Lay & Bennett)	10	L5
Moringuidae		
Moringua macrocephala (Bleeker)	R1	
Muraenidae		
Gymnothorax richardsoni (Bleeker)	14	
Pseudechidna brummeri Bleeker	12	
Chromidae		
Chromis caeruleus (Cuvier)	14	
Dascyllus aruanus (L.)	14	
Eleotridae		
Asterropteryx semipunctatus Rüppell	14	
Eviota gymnocephala Weber	14	
Gobiidae		
Paragobiodon echinocephala (Rüppell)	14	
Zonogobius semidoliatus (Valenciennes)	14	
Scorpaenidae		
Sebastapistes bynoensis (Richardson)	R1	

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10. CHECKLIST OF THE MORGAN COLLECTION OF MOLLUSC SHELLS FROM THE COOK ISLANDS

This collection of shells was made by the late Judge H.J. Morgan, who was responsible for its arrangement and for the identifications. The collection is now housed by the Cook Islands Library and Museum at Rarotonga, where it is available for study. The arrangement of this list follows that of Judge Morgan, except that species in each genus are arranged alphabetically. Specimens marked * were dead when found, all others were living. The list is included here by permission of the Council of the Cook Islands Library and Museum and of the Rev. Bernard Thorogood. The collection as determined by Judge Morgan includes over 200 species, derived as follows: Rarotonga 110 species; Aitutaki 59; Atiu 50; Mauke 19; Pukapuka 10; Manihiki 8; Penrhyn 3; Suwarrow 2; Palmerston 1.

Cypraea amphiperas ovum Linnaeus
Rarotonga: 66
C. annulus Linnaeus
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